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THE ORGANIZATION OF AN EFFECTIVE EXPLORATION DEPARTMENT[1]

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ABSTRACT

The author reviews the functions of a Land, Lease and Exploration Department in a large oil company, and describes in detail the integral parts. Criteria are furnished for the background of men suitable for the various positions, and a detailed organization chart is submitted which also shows the flow of information secured from the various field methods. Much stress is placed upon the need for detailed, routine reports. The part played by contracting geophysical exploration companies is also described, and the extent of the service which they should render is shown.

INTRODUCTION

For over half a century, drilling locations were determined by the most haphazard and fantastic methods imaginable (and some of this type of oil finding still persists and occasionally with phenomenal success, witness East Texas). After 1910, however, the anticlinal theory, which had been suggested as early as 1844, received wider appreciation, and soon justified its application by its success. When the value of this approach had thus been demonstrated to practical oil men, a wide and intensive search was instituted which eventually, and quite naturally, called the law of diminishing returns into play. At that time, geological methods *per se* proved too costly, too slow, and incapable of finding reserves as fast as the oil was withdrawn from the known and developed fields. As a result, other methods of oil finding have come into use and have justified themselves, in their turn, by their successes. These methods are in general called geophysical, as distinct from geological, although I wish to call attention to the thought that whenever a geologist drops his reference books for an altimeter, or plane table and stadia rod, he encroaches upon

[1] Address of the Retiring President, Annual Meeting, Society of Petroleum Geophysists, Tulsa, Okla., Mar. 19, 1936.

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the field of geophysics, for he uses the simplest and one of the earliest physical methods of measurements, that of optics.

Retracing our steps for the moment, we note that the advent of the anticlinal theory resulted in a very sudden appreciation of the need for men geologically trained. However, since there was no appreciable reserve of trained geologists, the universities were unable to supply the demand, and the high inducements offered to geological graduates resulted in far too many leaving before they had completed sufficient schooling to give them the advantages which ought naturally to follow from graduate study. Unfortunately, the curricula offered the undergraduate students in geology are notoriously lacking in any material training in the exact sciences. As a result, very few geologists have had more than the equivalent of as much as one course in college physics and one course in college mathematics. This lack of training in the exact sciences has made it difficult, if not impossible, for the average geologist to evaluate properly and to appreciate fully the significance of measurements made on second order effects, and to extrapolate in general from the data to the physical causes responsible for the effects measured; both of which are so frequently required in geophysics. In this connection, I quote from the address of the retiring vice-president and chairman of the Section of *Geology* and *Geography* of the American Association for the Advancement of Science, Dr. James B. Macelwane, S. J., as published in "Science," February 28, 1936.

"Geologists and seismologists are on exactly the same footing when looking into the depths of the earth. Both must observe from the surface. The difference lies partly in the methods and instruments with which they carry on their exploration, but partly also, and perhaps principally, in the frame of mind and the background of specialized training with which they approach the same problems. The geologist is trained to observe facts as they present themselves in the field and to balance them against alternative hypotheses; but he does so in a somewhat qualitative manner, for he depends largely on cumulative probabilities for his final decisions. His background usually will be mineralogical and petrographical; it will be physiographical, stratigraphical and frequently paleontological; but it will seldom be physical and mathematical. On the other hand, the geophysicist, generally speaking, whether he is working in pure seismology or in the applied and economic phases of the subject, will nearly always have come into the field with a background of physics and mathe-

mathics. This rigorous training makes him psychologically dissatisfied with observations and hypotheses in which there are too many variables. He wishes to isolate the phenomena and to devise instruments for the precise measurement of each. Indeed, he is restless until he can apply instrumental methods and can formulate a mathematical theory that will enable him quantitatively to correlate his observations and to predict further relationships. As he is fundamentally a physicist, he instinctively seeks to reduce field methods to such simplicity and precision that he can substitute a closed system in his laboratory and reproduce his results at will. Now, it seems to me that it is the interplay of these radically different outlooks and of the consequently divergent methods that has proven most fruitful in unraveling some of the apparently hopeless tangles of earth structure."

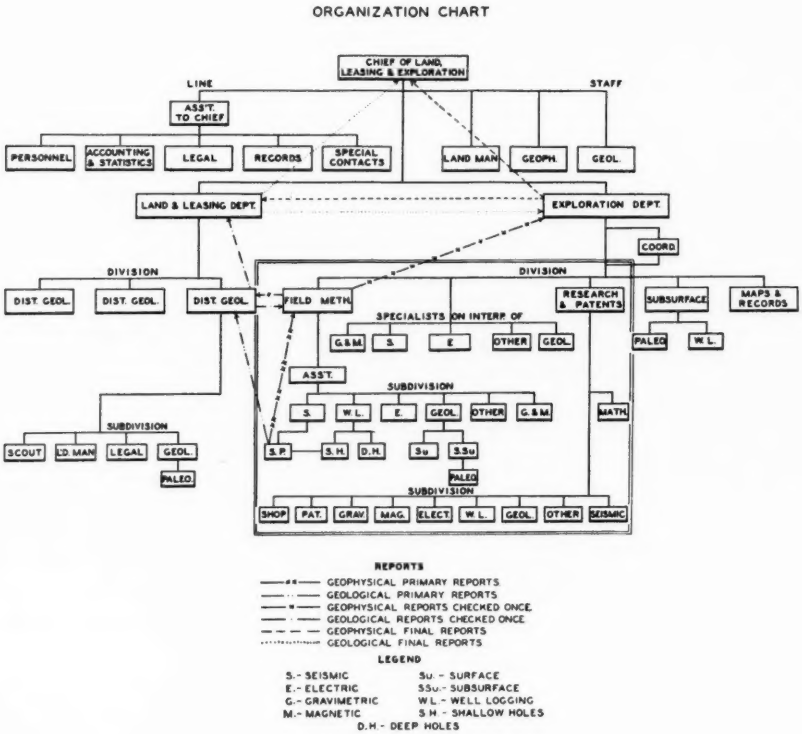
This interplay of radically different view points would operate to maximum advantage in the activity of a properly organized and staffed, Land, Lease, and Exploration Department. With this object in view, I am submitting an organization chart based on these principles, that: First, specialists have specialists for their immediate superiors; second, non-specialists are restricted to administrative positions; third, the giving of credit where credit is due is rendered certain by a prescribed system of original field reports; fourth, the proper assimilation of all knowledge gained from the different field methods is assured by a prescribed and progressive exchange of reports between line and staff. The unrestricted operation of these principles insures, first, that final action will be taken only upon recommendations based on a final report in which the original field data have been bled dry; and second, that essential information is never sidetracked, but always reaches the top for positive action.

The function of a Land, Lease, and Exploration Department is to secure leases for exploitation. Therefore, it would seem logical to divide this department into, first, a staff organization whose function it is to secure the information upon which these purchases will be made most favorably, and second, into a line organization devoted to the actual purchasing of these leases. This has been effected by breaking down the organization first into a Land and Leasing Department (line) and an Exploration Department (staff), as shown on the chart.

CHIEF OF LAND, LEASING, AND EXPLORATION

The Chief of Land, Leasing, and Exploration has reporting to him, first, the Chief of Land and Leasing; second, the Chief of Exploration;

and third, his adjutant, or assistant, in charge of Personnel, Accounting and Statistics, Records, Special Contacts, and the head of his Legal Department. No more need be said about the duties of this assistant, except that I believe the value of properly compiled pertinent statistics has not yet been fully appreciated. Further, under Records, I include not the ordinary files of correspondence, but special



and routine reports pertinent to the operation of the whole department.

This assistant, however, is only one of the needed General Staff. A staff geologist as well as a staff geophysicist is required to assist in laying out the plans for major campaigns in old as well as new areas. Finally, a capable land man should be included, to investigate the land problems involved in such campaigns, and to handle important local as well as non-resident land problems.

CHIEF OF LAND AND LEASING

The duties of this position are such that geology, alone, and land experience alone, are each necessary but neither sufficient by itself. Trading experience is highly desirable, but so is a sense of values, for this latter is important not only in acquiring holdings, but also in their regular evaluation as rentals fall due. Of the two, the sense of values is more necessary, for the introduction of the automobile has materially reduced the field of activity in horsetrading. Under the circumstances, I am of the opinion that this post is best filled by a geologist with the proper understanding of land problems.

DISTRICT GEOLOGISTS (IN SOME COMPANIES, DIVISION GEOLOGISTS)

The various district geologists report directly to the Chief of Land and Leasing, and each has his own organization consisting of a scout, a land man, an attorney, one or more field geologists, and a paleontologist. In general, the paleontologist will work under the field geologist. Since all of us are more or less familiar with the operation of this department, I will go no further into the detailed routine at this time.

Since such innovations as I am going to recommend will appear primarily in the Exploration Department, I shall try your patience by going into much more detail in the discussion of this organization.

CHIEF OF EXPLORATION

Under the Chief of Exploration are five divisions: First, field methods; second, maps and records; third, research and patents; fourth, subsurface; and fifth, interpretation specialists. In addition, his immediate assistant is in charge of the coordination of the work of these five departments, and should be a man trained in an exact science who has shown not only administrative and executive ability, but who also possesses a positive personality in addition to his scientific attitude. The smooth, efficient, fact-gathering and interpretative operation of this department will be largely dependent upon the choice of this coordinator.

SUB-SURFACE

The duties of the sub-surface division might be considered purely historical if it were not for the relatively untouched field of correlating detailed sub-surface information (a relatively recent geophysical contribution) with geophysical interpretations, so that discrepancies in

the latter, revealed by later development, can be called to the attention of the Chief of Exploration. The chief of the sub-surface division gains his information from paleontology and well-logging by electrical and other recognized methods.

RESEARCH AND PATENTS

The research director should, preferably, be a physicist. It is possible that a properly qualified man, not a physicist, might be found within an organization; however, if one were looking on the outside for such a man, he would scan a list of physicists first. If the research director is not a physicist, it becomes necessary immediately to establish an assistant's post to be filled by a physicist, or to divide the research division into different subdivisions, each headed by a physicist. The research director then immediately drops to the level of an administrator or executive, concerned only with the formulation of policies, a needless complication. In the research division, attention is concentrated on the perfection of existing methods, the development of new methods of prospecting, electrical well-logging, and geological research by competent geologists (who need the close contact with physicists, engineers, and chemists which their association with the scientists in the research division affords them).

The part of patent attorney will be very hard to fill. Patent attorneys as a rule lack the background in physics and engineering which they ought to have in order effectively to relieve research men of much tedious desk work and to furnish reliable opinions on patent matters. Attention is called to the fact that the position of a company in patent matters should be offensive as well as defensive, which is the logical reason for including patents as a research function. The offensive use of patents involves the securing of basic patents on inventions made by company scientists and the purchase of valuable patents granted to outsiders. As a matter of defence, patents, not necessarily basic, must be secured on the methods and apparatus employed by the company; further, investigations must be carried out with a view to the anticipation and eventual invalidation of dangerous patents held or controlled by outsiders. In these latter investigations, the value of the acquaintance of the research scientists with the technical literature can hardly be overestimated.

The other subdivisions of the Research and Patent Division are headed by specialists in gravitational, magnetic, electrical, well-logging, seismic, geological, and other recognized or potentially valuable

methods of exploration. Each of these specialists with one exception must be a physicist with thorough training in mathematics. A wise precaution would be to not infrequently rotate these specialists from one subdivision to another, thereby gaining not only an improvement in general experience, but also the beneficial effects of new minds on old problems.

Since the function of the Research Division is to bring order out of chaos, the physicist in charge should have as his assistant a competent and versatile mathematician.

MAPS AND RECORDS

All field records and maps are filed and stored in the subdivision of Maps and Records. Competent draftsmen prepare inked base maps for intermediate and final reports.

FIELD METHODS

The Chief of Field Methods should certainly be a physicist, competent to direct exploration and interpretation in all recognized field methods, in close cooperation with the Research Division. His assistant is primarily responsible for the administration of duties incident to the routine operation of the field crews. There is a subdivision for each exploration method, although two or more methods can frequently be combined advantageously. Surface and subsurface geology are included for the purpose of collecting and furnishing regional subsurface maps for the general use of the subdivision.

In the organization of a seismic field party, a very common and serious defect calls for comment. In too many cases there is too much specialization. There are observers who do not know computing, there are computers who know nothing of the field procedure, and party chiefs who are too frequently recruited from the ranks of such computers. As a result, there exists no communion of interest, no common understanding of the problems confronting the party, and no basis for such discussion as may lead to their solution.

I feel convinced that computers should be trained as competent observers, and vice versa, and that party chiefs should be chosen from those computers and observers who can handle both jobs well and in addition display the required managerial ability.

INTERPRETATION SPECIALISTS

Reporting directly to the Chief of Exploration are specialists in each of the field methods. Their duties are to make independent

checks on all field reports, as there is a noticeable difference in the interpretation of hot and cold data. The field party chief will usually put too much weight on poor data taken in difficult terrain, for he unconsciously feels he must justify the unusual expenditure. To the specialist checking the work, however, the immediate past history of the data is of little or no importance, so that he will weigh the data more rationally. Both viewpoints are important, for the best interpretation frequently lies midway between the optimism of the field man with his hot records, and the conservatism of the checker with his cold data.

If Nobel Prize Laureates can disagree on such phenomena as cosmic rays, and if discussion can improve the interpretation of such phenomena, then certainly independent but competent interpretations of geophysical data are to be sought rather than avoided.

REPORTS

The two most serious errors to be guarded against in any organization are, first, that action might be taken upon an undigested recommendation, and second, that a pertinent recommendation might never reach the place where proper action could be taken. The first is an act of commission, the latter a sin of omission. A proper system of reports should materially reduce both hazards.

The system recommended here is one of checks and comments. Thus, the original field report is sent by the seismic party chief both to the district geologist for information, and to his immediate superior for transmittal to the subdivision of Interpretation for checking. The district geologist then comments in writing on this report, sending a copy both to his opposite number (the Chief of Field Methods) for information, and to his superior for checking.

The subdivision of Interpretation sends a copy of the checked report to the district geologist for information, and another copy to the Chief of Exploration (for checking). The district geologist comments in writing on the checked report, sending copies to the Chief of Field Methods and to his superior.

The final report is made by the Chief of Exploration both to the Chief of Land and Leasing and to the Chief of Land, Leasing, and Exploration. The answering comment on this report is made by the Chief of Land and Leasing to the Chief of Exploration and to the Chief of Land, Leasing, and Exploration, who takes final action.

The advantages of this report system are:

1. Since written reports are required of the field party chiefs, there should be no eventual question as to the relative merits of the individual party chiefs. Credit should readily go where credit is due, and vice versa.

2. Since each report requires answering comment, and notification is thereby made up the line that check reports are forthcoming, a simple tickler file should prevent undue delay in comment or check.

3. Action need be taken only after the original data have been bled dry by exhaustive checks and double checks, so that the Chief of Land, Leasing, and Exploration is assured of reports, for his guidance, which incorporate all the knowledge gained about the area in question by all the field methods prior to the date of the last primary report.

While the outstanding apparent disadvantage of this system is the delay seemingly required for final action, still I wish to point out that in many present cases the available data are at hand but have never been properly used. As a matter of fact, in those cases where time is of the essence, natural delays will be eliminated by such a smooth, properly functioning organization. Cases will, of course, come up where for the time being this report system will have to be passed in favor of a series of conferences. In the final analysis, there must be mutual understanding and mutual tact throughout, for in this as well as in any other organization, personal friction must be avoided.

CASE OF THE SMALL COMPANY ORGANIZATION

Under "Small Companies" I refer to those organizations, usually, though not always, small, who contract for all or part of their geophysical exploration. Too often the district geologist of such a company is the court of last resort in geophysical exploration, and as a result considerable geophysical exploration is sold on the primary basis of emotional appeal much as patent medicines are still sold to country farmers. As a result the interpretations and methods too frequently accepted are, to say the least, highly original, and are discussed with the same fluency and background as are the stars by a Hollywood astrologer, or Newton's Laws and other physical phenomena by those to whom Dr. Blau has referred as "Black Magicians."[3] Therefore, I feel that I cannot recommend too strongly that each such company employ a competent physicist who is qualified

[3] Geophysics, pp. 1–8, Vol. 1, No. 1, Jan. 1936.

to check not only the actual results, but also the methods of securing the data and making the interpretation.

For convenience, I have blocked off that part of the Exploration Department which is supplied by the contract companies. Often the oil companies feel that they are hiring a particular party chief, but as a matter of fact they are, in effect, hiring the whole of the organization enclosed within the "box." Therefore, the choice of a contract party should be determined not only upon the field party or party chief in question, but also upon a critical examination of the rest of the contract organization. In effect, the contract company should guarantee research, development of technique, and checking facilities, and should also be in position to render patent advice. From this viewpoint, it is apparent that competent contracting companies should represent a savings to the industry, since in their operations they will eliminate much duplication of activity. As I pointed out in my foreword in Geophysical Transactions, 1933, "If advances in the art are to be made by the consulting companies, they must have not only sufficient profits to invest in experimental work, but also capable personnel willing to carry on experimentation." This means that the encouragement of or the insistence upon price competition between contracting companies may well be a shortsighted policy, for thereby the money available for their, and incidentally your, research program may be reduced to a point where the maintenance of these facilities, and therefore further progress in the art, will become greatly impaired.

There is no reason why the geologist should be disturbed at the thought of the proposed organization. In the line organization his status has not been altered materially, while in the staff organization an effort has been made to utilize his special knowledge. Moreover, his responsibilities are increasing in other directions. He is particularly fitted to work on problems associated with the economical and rational utilization of the reserves at hand. This is shown by the excellent results obtained in the drilling of such fields as Tomball with its thin pay horizon.

The problem of discovering additional reserves is being left more and more to the geophysicist and it is only logical that this increase in his responsibilities should be accompanied by the delegation of powers commensurate with these responsibilities.

A PROPOSED GEOPHYSICAL PROGRAM OF EXPLORATION FOR NEBRASKA AND THE DAKOTAS

JOHN H. WILSON[1]

ABSTRACT

The known geological information, particularly with reference to possible oil-producing horizons, is discussed briefly.

A method is proposed whereby the area is subjected to a reconnaissance seismic survey to determine the location of the major structural features, followed by other methods of successively higher resolving power in the favorable areas outlined by the reconnaissance.

INTRODUCTION

The frontiers of exploration for oil and gas expand in successive waves of differing methods outward from the old centers of activity. Ordinarily we would expected the activity in any region to be roughly proportional to the demand for oil and the geological merits of the area and inversely proportional to the square of the distance from production, however, there are many anomalies in such a field of activity. Such an anomally is the area including Nebraska and the Dakotas.

The area has not been held in high esteem by the oil industry in general because of:

1. *Lack of production in the area.* To some prospectors lack of producing fields is a fatal defect for an area. It is fortunate indeed that pioneers with greater vision arrived in the present producing states before them.
2. *Lack of knowledge.* Insufficient deep wells have been drilled in the area to give the desired detailed information on stratigraphy and structure, except along the margins of the basins. The area as a whole, does not readily lend itself to the geological method of attack.
3. *Failures of important tests.* A relatively small number of wells have been drilled on good geological information and these have been dry. Study of these cases usually show that most of these wells were located on structural features in which:
   a. The most probable producing formations were absent, or
   b. The most probable producing formations were under very little cover of superadjacent formations, or

[1] Colorado Geophysical Corporation, Denver, Colorado.

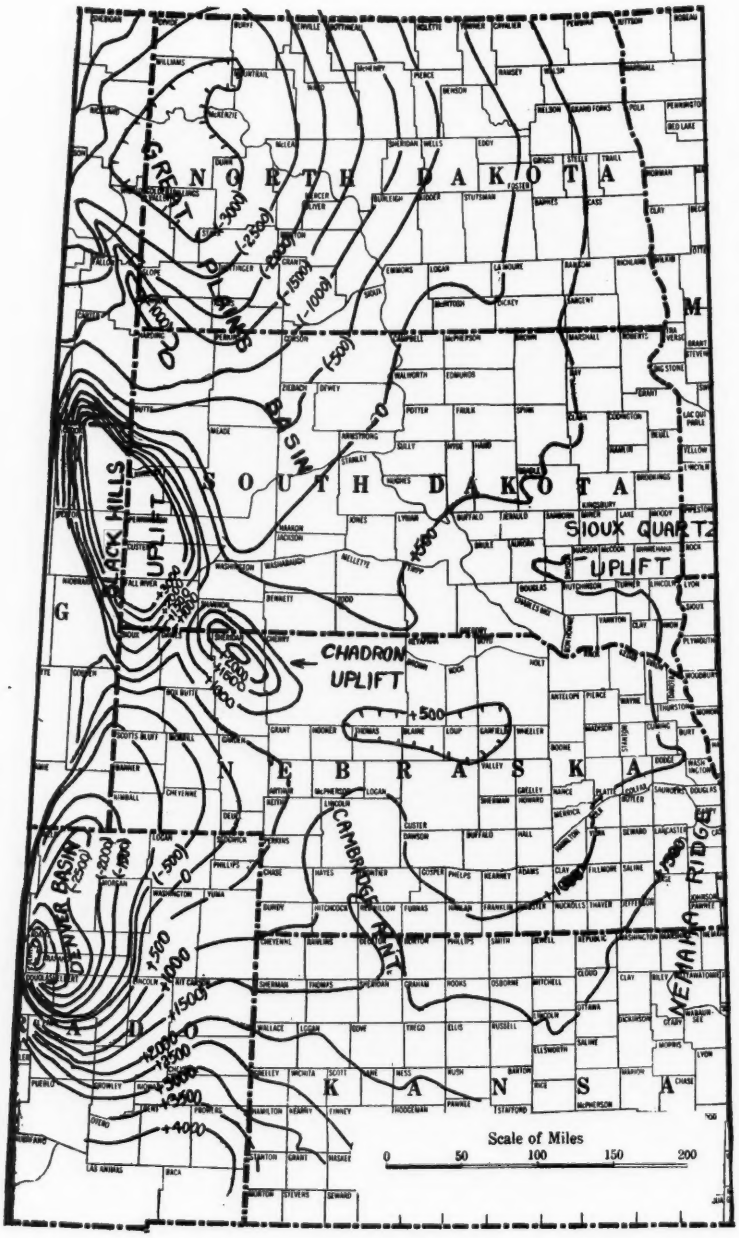


FIG. 1. Subsurface map of a portion of the Great Plains area. Contours on top of Dakota sandstone with interval of 500 feet

c. The full geological section was not penetrated, or
d. There is a question if the subsurface structure exists in as favorable form as indicated by consideration of surface conditions.

4. *Belief that the sedimentary section is unfavorable for oil and gas.* In some areas of uplift the sedimentary section is thin and of character generally regarded as unsuitable as source beds for oil and gas. It seems probable, however, that these conditions are local and not characteristic of the general area. There is a tendency to hurriedly condemn new areas, for we can all remember prophets who were unfavorable to Kansas west of the Nemaha granite ridge, or the Panhandle of Texas, or West Texas, or New Mexico, on the basis of supposed unfavorable sedimentary sections.

GEOLOGICAL CONDITIONS

The major structural feature of the area is the Great Plains basin, with its deepest place in western North Dakota. This basin is more or less continuous with the Central Nebraska basin and the Salina basin of Kansas. It has been called the Lemmon basin where it crossed the line of North and South Dakota, and the Williston basin in western North Dakota.

The eastern margin of this basin is formed by the Nemaha granite ridge and Sioux quartzite area in the eastern Dakotas. The western margin is formed by the Cambridge anticline (the northwest extension of the Central Kansas uplift), the Chadron uplift, the Black Hills, and the folded areas of eastern Montana.

A generalized subsurface map of the region, (Fig. 1) indicates the major structural features.

This large basin is filled with sediments ranging in age from Cambrian to Tertiary and including the age equivalents of the producing horizons of surrounding areas. The writer, for one, is willing to affirm that such a basin is worthy of consideration and should be explored for oil and gas.

In Table I, have been listed the more important productive horizons of the surrounding areas.

HISTORY OF EXPLORATION

The area has been subjected to sporadic campaigns of geological exploration and to a certain amount of drilling, usually poorly financed and directed.

TABLE I

POSSIBLE PRODUCING HORIZONS

System or Period	*Horizon*		*Distribution in region*
	Name	*Place of Production*	
Cretaceous	Judith River	Baker-Glendive anticline (gas)	Probably present in western North Dakota and may be productive on structures in that area.
	Muddy Newcastle	Osage & other fields in Wyo. (oil) Greasewood, Colo. (oil)	Probably extends over much of western part of basin. Possibilities of stratigraphic traps where thinning out or where overlapped.
	Dakota	Various fields in Wyoming	Probably extends over nearly whole of basin. May be overlapped at various places on eastern side of the basin.
	Lakota	Various fields in Wyoming	Probably generally present but subject to much irregularity of deposition.
Jurassic	Sundance	Lance Creek (oil) & elsewhere in Wyoming	Probably extends over much of western part of area but overlapped to the east, presenting opportunities for stratigraphic traps.
Permian	Embar	Various fields in Wyoming	The probable equivalent, Minnekahta limestone, is present over portions of the western part of the area but is not of favorable character. A different type of Permian prevails in eastern Nebraska.
Pennsylvanian	Topeka, Oswald, etc.	Various fields in central western Kansas	Probably present over part of Nebraska. In southwestern Nebraska, the section is more nearly that of Wyoming (Tensleep and Amsden). In western South Dakota it is similar to that of the Black Hills (Minnelusa) and in western North Dakota it is probably similar to the Montana section (upper Quadrant). Possible Pennsylvanian producing horizons are probably absent from much of eastern North and South Dakotas. Over major uplifts the Pennsylvanian is often thin or absent.
Mississippian	Mississippian Lime	Kansas	Mississippian limestones of Boone age are probably present in much of Nebraska. The Pahasapa limestone of the Black Hills extends over much of western South Dakota. The upper Mississippian (lower Quadrant) and the lower Mississippian (Madison-Pahasapa) are probably both present in western North Dakota but may be thin or absent in eastern North Dakota.
	Madison Lime	Wyoming and Montana	

TABLE I (*Continued*)

System or Period	*Horizon*		*Distribution in region*
	Name	*Place of Production*	
Ordovician	Maquoketa ("Viola")	Kansas fields	Moquoketa limestones are probably present in much of central and eastern Nebraska. The Whitewood limestone of the Black Hills which appears to be the approximate equivalent is locally present in western South Dakota but has been removed from wide areas due to Pre-Mississippian erosion. A dolomitic section of Richmond age has been found in several wells in central North Dakota.
	Wilcox sand (St. Peters)	Kansas fields	Appears to be present in much of central and eastern Nebraska and probably also in parts of the basin in the Dakotas not yet tested.
Cambrian	Arbuckle (Siliceous lime)	Kansas fields	Appears to be present in much of central and eastern Nebraska but absent from older uplifts. May be present in parts of basins in the Dakotas not yet tested. Does not appear to be present in the Black Hills area.

General exploration has not been very successful because:

1. Much of the northern part of the area was covered at one time by Continental glaciers. The movement of the ice across the surface of the land so distorted the surface formations that structural interpretation is difficult.
2. Much of the area is covered by windblown sand, glacial drift, soil and late Tertiary formations that conceal the structure of the underlying formations.
3. The Cretaceous formations are largely shale and in many places do not contain key beds adequate for accurate mapping.
4. Where key beds do occur in the form of hard ledges, these are often slumped so as to make mapping of them of questionable value.
5. The rapid thinning of the Cretaceous eastward results in the condition that in some areas the upper part of the Cretaceous dips eastward and the lower part dips westward with consequent uncertainty as to the true subsurface structure.

The area seems well suited for geophysical exploration, and the pioneers along the geophysical frontiers were the magnetometer men

of 1929 and 1930, who covered much of Central Nebraska and isolated areas in the Dakotas. The magnetic campaign faltered and finally stopped in the early thirties under the combined influence of the depression and loss of confidence in magnetic methods.

The next invasion, that of the seismograph, began in 1934, is still continuing with promise of success, and appears to be the ideal method of exploration of the area.

The question of whether or not to explore this area has already been answered. The exploration has already begun due to advantages that accrue to the company first covering a new area with a new method of adequate resolving power, the increasing lack of virgin territory in the older producing states, and that competition for the reserves of the future which will not cease until the last field is found.

CHOICE OF METHODS

The question now before the exploration industry, for industry it is, is where and how.

The area is so large that several years will be required to make even a reconnaissance seismic survey. Where shall a company desiring to start seismic exploration begin? The usual, but not necessarily the best point, is the location of a block of acreage that has been submitted, or the location of a structure suggested by surface, subsurface or other geophysical studies. One may start on an area so selected, and if good reflections are obtained, spend a year or more in detail work in this local area only to find later that this spot is unfavorable because of lack of section or on account of regional structural considerations.

The first process of exploration should be one of selection of areas to be covered. Ordinarily we would depend upon the geologist to outline for the geophysicists those areas of favorable section and favorable regional structure. In this case the geologist will tell you that too few wells have been drilled to allow any but the vaguest conclusions as to structural and stratigraphic conditions, particularly with reference to the Pre-Cretaceous. Unfortunately, the competition in these new areas will not wait for the drilling of wells for such scientific information.

In the past the cheaper methods, usually of less resolving power, have been used in the preliminary reconnaissance work. The writer wishes to propose a radical departure from this procedure and proposes to use the reflection seismograph, one of the more expensive

methods, as a reconnaissance tool. The recommended method would be to take reflection seismograph records at intervals of about ten miles, throughout the area to be investigated. The spacing is purposely made large enough so that it will not indicate local structure, as the temptation would be to stop and detail rather than to get the general picture and attain the objects of the reconnaissance.

The objects of such a reconnaissance survey would be to

1. Determine the thickness of the sedimentary section at each location. Past experience in the area has shown this can usually be done with the requisite degree of accuracy, although there may be local areas in which the results are not satisfactory.
2. Determine the areas in which good reflections can be obtained. If stations are properly selected, they should give a fair assay of the workability of a region.
3. Determine the location of regional features. In areas where the Niobrara limestone is at a sufficient depth, correlatable reflections can be obtained even though the stations are ten miles apart. From the reflections below the Niobrara the thickness of Pre-Niobrara section can be estimated, and some idea obtained as to Pre-Cretaceous arches and basins.

From the information obtained we can select for local detail work economically attractive areas where the regional structural and stratigraphic conditions are favorable and where good reflections can be obtained.

Having so selected our area of exploration, the detailed studies can be made in the usual order, that is, using methods of successively higher resolving power on the various prospects noted in the preliminary geological and geophysical work.

VISUAL PRESENTATION OF ELASTIC WAVE PATTERNS UNDER VARIOUS STRUCTURAL CONDITIONS

FRANK RIEBER[1]

ABSTRACT

The usual form of reflection seismograph operates satisfactorily over simple structural conditions, but frequently fails to obtain part or all of the desired information when structures are steeply folded, faulted or otherwise complicated. The reasons for this are plainly evident if the paths of the waves in the earth can be visualized. This has been done by the use of a technic originally developed for acoustical measurements.

A miniature explosion radiates waves into various models of structure, where reflection and diffraction take place in the same manner as in the earth. The various moving waves are actually photographed in flight. A series of plates is presented, showing wave patterns in various types of structures, ranging from simple to complex. A new type of equipment and technic are briefly described, with which exploration may be carried into the more complex structural regions successfully.

The appearance of an ideal reflection record is well known to all of those familiar with seismograph work. Definite, well marked bands or patterns of vibrations, more or less parallel to each other are seen to traverse the record. These bands persist in amplitudes sufficient to be readily seen and marked, for a considerable length of record.

The good shooting conditions, permitting such records to be taken, occur chiefly in regions where strata are definite and well marked, and relatively flat lying.

The appearance of a poor or low grade record is, unfortunately, almost as well known, especially to those who have had occasion to attempt reflection shooting in regions of relatively steep folding or faulting. These poor records, while they contain vibrations of good amplitude persisting for a satisfactory distance down the strip, show very few patterns or "line-ups" which might be marked as reflections. Furthermore, it is frequently impossible to plot from them any consistent structural condition.

Records of this latter type are customarily marked "N. R.," presumably meaning "no reflections." However, a simple consideration of the space geometry of the reflected wave paths will show that, in very many cases, such confused records are due to the presence of too many, rather than too few, reflected waves.

Consider first the fact that such poor records are very frequently obtained in the vicinity of steep folding and faulting, where the

[1] Rieber Laboratory, 1007 Braxton Ave., Los Angeles, Calif.

rapidly changing attitude of the beds must necessarily result in simultaneous arrival of groups of reflections from a wide variety of different directions.

For example, take the well known case of shooting over a syncline. If we could by some means remove either side of the syncline and shoot for the other side alone, we might expect to get a high grade record showing a succession of relatively parallel bands from which the plotted results would correspond accurately to the dip of the beds in that side of the structure.

Ordinary shooting methods do not permit us to make such separations, however, and reflections from both sides of the syncline enter the system with equal freedom and appear with equal prominence on the record. The vibration patterns thus produced will fall in a criss-cross fashion on the record, giving a result that is difficult and often impossible to read.

As is well known, the clearest records are obtained in regions where all reflections arrive at the receiving system from substantially the same direction. Steeply folded or faulted regions contain very few places where this ideal condition prevails. Hence the predominance of poor records and the great difficulty of reflection exploration in such places.

The writer has devised a receiving system,[2] employing a sound track record and an optical analyzer. This system has been in field use for some time, in locations where structural conditions were sufficiently complex so that the usual type of visual record was unsatisfactory. In such places, the new system has done exactly what was expected of it, namely, broken down the complex group of arriving waves into its components. From these components it has been possible to map structure quite satisfactorily.

A majority of the identified individual waves recovered from the complex vibration by the analyzer, under such conditions, plot satisfactorily as strata, and permit the delineation of the structure. A smaller, but very definite number of the returned waves, however, cannot be plotted as strata without conflicting seriously with the majority evidence.

This minority of wave trains is quite real, and the places in the earth from which they are returned to the receiving system are quite

[2] "A New Reflection System with Controlled Directional Sensitivity," by F. Rieber, January 1936 issue of "Geophysics," Vol. 1, No. 1, p. 97. This system is the subject of several pending applications for patent.

definite and can be separately identified from several successive shooting or receiving positions at the surface.

The question then naturally arises as to what geologic conditions, other than stratification, capable of returning a wave to the surface, might exist in the structures under examination.

The possibility suggested itself that some of these waves were diffractions rather than reflections. Theoretically, such diffraction patterns could arise at any place where stratified material is broken or faulted, or suffers any abrupt change in its elastic properties, its density, or its power to absorb vibrations, or in short, any corner or edge where there is a change of mechanical impedance.

In other words, it seemed probable that, if we were to explain all of the waves which were analyzed out of the complex earth vibrations over steeply folded structure, it would be necessary to go a step beyond the ordinary geometric paths assumed for reflected waves where the angle of incidence equals the angle of reflection.

Accordingly, an attempt was made to reproduce, in model form, certain possible elements of structure, and to photograph the actual wave patterns produced when a compression wave impinged on the model.

The technic for doing this has occasionally been used in acoustical investigations. The writer is greatly indebted to Dr. Vern O. Knudsen and Prof. L. P. Delsasso, of the University of California at Los Angeles, for information on this earlier technic, and also to Mr. B. F. McNamee and Mr. Frank McCullough, who carried out the difficult and exacting work of constructing the actual apparatus[3] used in these investigations, made the models, and photographed the wave patterns here presented.

Briefly, the technic is one of shadow photography, no lens of any sort being employed. A bright electric spark, lasting only about one millionth of a second, is spaced about four feet from a photographic plate. The model of the structure to be investigated is placed part way between the spark and the plate, in such a position that its shadow will be photographed.

If no sound waves are present in the field between the light source and the plate, the shadow of this model will be the only thing shown in the photograph. The rest of the field will be uniformly exposed to

[3] An article by B. F. McNamee, describing in detail the mechanical and electrical features of this equipment, is to appear in a forthcoming issue of *Electronics* magazine.

the light from the spark and will correspondingly show uniform photographic density.

If an abrupt sound wave happens to be passing through the field, however, the light from the spark will be bent slightly at the places where it passes through the denser air of the wave front. This bent light will be superposed upon other illumination arriving directly on the plate from the spark, thereby causing a dark line. The part of the plate from which the bent light was diverged will show, correspondingly, as a lighter line.

Only a very abrupt wave front of sound may be pictured in this manner. Such a wave, fortunately, can be created by another electric spark, acting, in this instance, as an explosion rather than as a source of light. Such an explosion, or sound spark, is placed above the structure model, its location being indicated in the subsequent plates by the shadow of its electrode structure, as cast on the plate by the light spark.

In operation, this sound spark or explosion is repeated about five times per second, sending a succession of sound waves down to strike on the model. Following each sound spark at exactly the correct interval is a light spark, so timed as to catch the sound wave at some desired point in its progress, and flash an image of this wave against the photographic plate.

A ground glass can be substituted for the plate, and the actual shadow of the wave may be observed. For any adjustment of the apparatus the wave pattern is practically stationary. Turning a knob, which adjusts the very critical time interval between the sound spark and the light spark, results in causing the wave image to move forwards or backwards. The downgoing wave front may thus be advanced until it just strikes upon the structural element to be investigated, at which point reflected or diffracted waves will begin to appear. Advancing the downgoing wave still further will cause the returned waves to progress a corresponding distance back from the surface. Fig. 1 shows the arrangement in somewhat diagrammatic form. The electrical control circuits regulating the interval between the sound spark and the light spark are purposely omitted from this diagram. These circuits, however, as will be immediately recognized, are the most critical part of the equipment. They must control the time interval between the successive sparks to an accuracy of approximately one millionth of a second, and must permit the con-

tinued repetition of these spark groups with this identical time interval, regardless of such variations as may occur in the fluctuating regions of heated gas in the spark gaps themselves.

The photographic portion of the equipment is contained in a box about one foot high, one foot wide, and four feet long, at one end of which a plate holder and ground glass arrangement is mounted, similar to that on a camera. A shutter is also provided, interlocked with the electrical mechanism, by the use of which the plate may be exposed to the light of a single spark only.

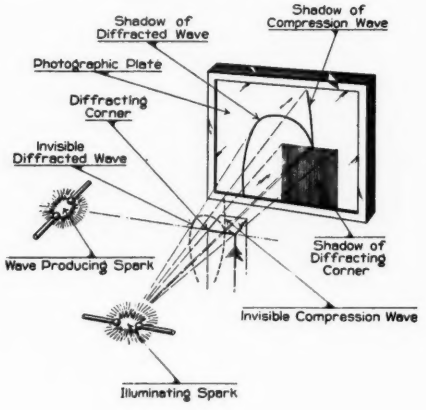


FIG. 1

Referring now to the models, the first of these is intended to represent a succession of planes of stratification, and to show how a downgoing wave, passing through this succession of planes, would send back from each plane a reflected component. It was accordingly necessary to find material through which a compression wave could pass without great loss, but from which a small portion of the wave would be reflected. Fine mesh copper screen was used for this purpose, and a model showing four successive stratifications, with a wave passing through all of them, is shown in Fig. 2. It will be observed that the downgoing wave does not lose appreciable energy in passing through the successive strata. It is also of interest to note that several of the reflected waves, in passing upwards through the strata are in part reflected downwards again.

Two other points of minor interest appear in Fig. 2. One is a second downgoing wave, appearing just below the location of the explosion. This is due to the reflection of the wave from the original

explosion, where it struck the top of the box. Even though lined with felt for the purpose of absorbing such waves, this top sent back a sufficient impulse to be clearly recorded. The center of this down-going wave is missing, having been broken up on passing through the heated air in the spark. A second point of minor interest lies in the clearly shown diffraction pattern from the individual wires of the screen, which gives a definite texture to the background region in the vicinity of the explosion spark.

FIG. 2

With the exception of this first screen model, the subsequent plates are all from models employing a single structural element of material through which the original waves did not pass. This choice was made in the interests of simplifying the early part of these investigations by confining them to the wave patterns produced by one individual element. A succession of such elements would obviously produce a succession of later phenomena, following one another at definite time intervals.

Fig. 3 shows the wave pattern produced when a broken-off stratum is introduced into the field. Such a pattern would be expected for each successive bed in a region of normal faulting. The original or down-going wave is clearly seen as a large circle centering at the location of the explosion. Above the stratum, starting where the original wave meets the stratum, a reflected wave will be seen curving up towards the explosion, where it suddenly changes to a weaker or diffracted wave pattern of approximately circular form described around the

upper corner of the broken-off stratum as a center. A second circular diffracted pattern will be seen described around the lower corner of the stratum as a center and extending until it strikes the lower surface

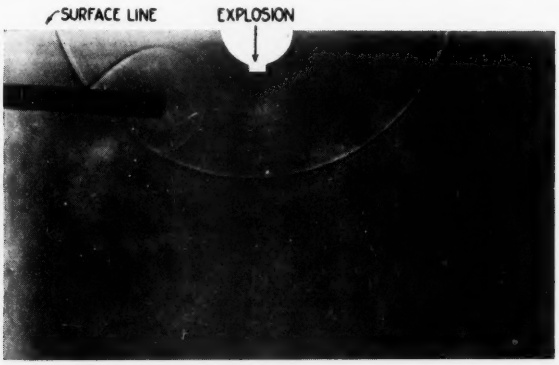


FIG. 3

of the stratum. The relative intensities of the reflected and diffracted waves as shown in this plate indicate that diffraction patterns are of sufficient magnitude to be useful in indicating the presence of faulting,

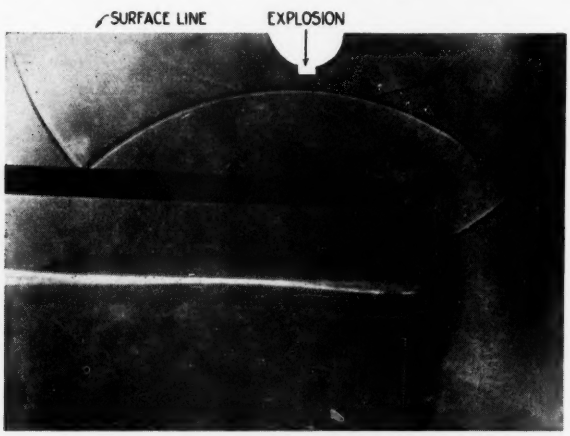


FIG. 4

provided appropriate means are used for separating and identifying diffracted waves in the presence of much stronger reflected waves from other directions. This problem will be gone into in more detail later.

Fig. 4 shows the same type of diffraction pattern from the same type of broken stratum, with the sole difference that the stratum extends past the explosion. The diffracted wave, while slightly weaker, can be very definitely seen here also.

Fig. 5 shows a normal fault located almost directly below the explosion, a slight but definitely noticeable diffraction pattern being visible here also. It seems rather evident that if diffraction patterns are to be used as a means of locating normal faulting this would be best accomplished by placing the explosion to one side of the fault, rather than directly over it, in order that the diffracted waves may arrive at the receiving system from a direction substantially different from that of the reflected waves.

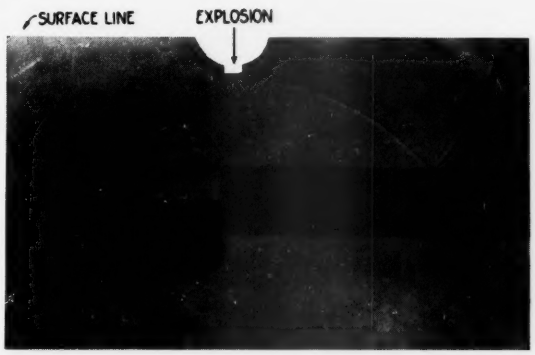


FIG. 5

Fig. 6 shows a normal fault to one side of the explosion. The reflected wave from the stratum on each side of the fault is clearly seen, as are also the two diffraction patterns due to the discontinuities in the upper and lower strata. This plate will be used as a basis for the diagram given later as Fig. 15, showing the problem of fault location in greater detail.

Fig. 7 shows another fault, with the two reflected waves and several diffracted waves clearly evident. The downgoing waves seen below the strata have not passed through them, as might be supposed, but have passed by them in front and behind the model, which did not extend to any great distance in the direction to and from the plane of the picture.

Fig. 8 shows another fault in which each of the wave patterns is due largely to reflection, and only a small portion to diffraction.

Fig. 9 shows the same model after the waves have progressed somewhat farther. It is clearly evident that waves from two different directions will shortly reach the surface slightly to the left of the explosion.

FIG. 6

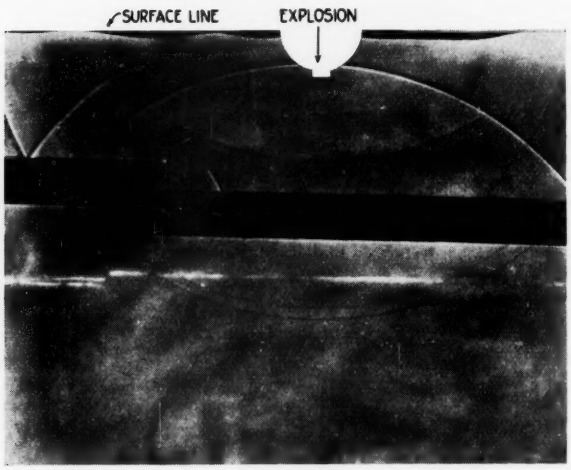


FIG. 7

If a receiving system were placed here, the identification of both of these arriving waves would be necessary if the structural conditions were to be properlp defined.

Fig. 10 shows a sharp fold which has returned some reflected and some diffracted energy.

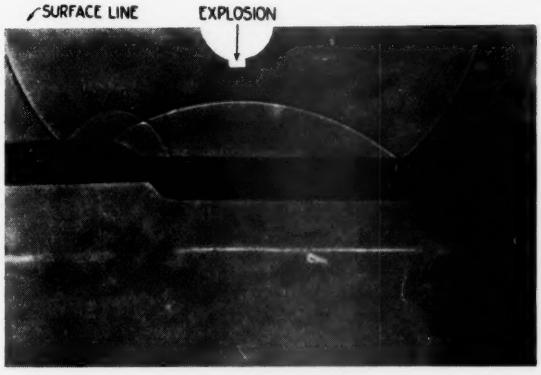


FIG. 8

Figs. 11 and 12 show two successive stages in the return of waves from a sharply folded syncline. Here again it is quite evident that a number of waves from this group will shortly reach the surface to the left of the explosion, more or less simultaneously, but from a number of different directions, thus presenting a problem in separation and identification.

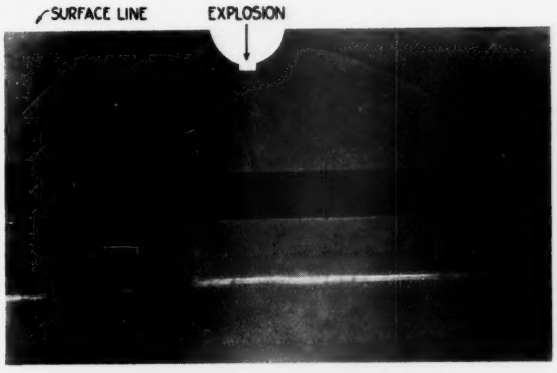


FIG. 9

Figs. 13 and 14 show two successive stages in the spread of the reflected and diffracted wave pattern from a sequence of sharp folds or wrinkles. Here, again, it is evident that a complex wave pattern containing more or less simultaneous arrivals from various directions

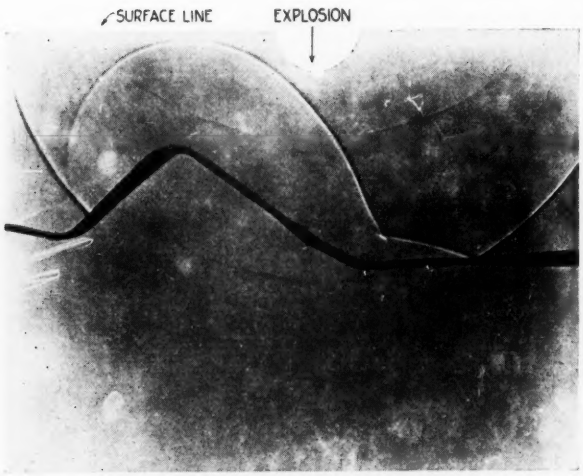
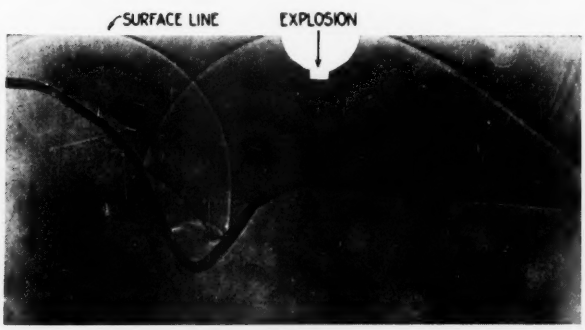
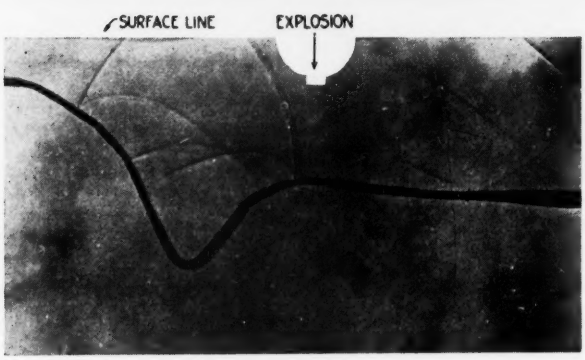


FIG. 10





FIGS. 11 AND 12

will ultimately reach the surface. Two such waves, in fact, may be observed on Fig. 14, just reaching the surface to the left of the explosion.

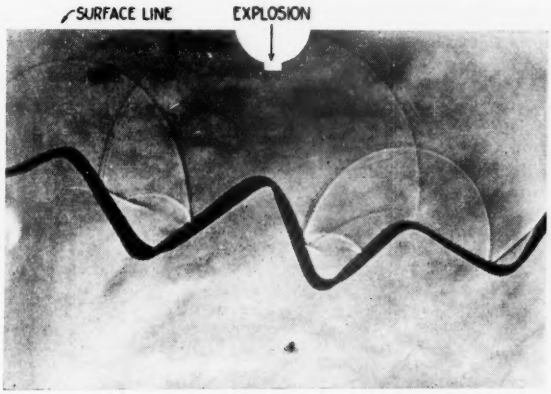


FIG. 13

From all of the foregoing two definite points may be emphasized, both of which have great importance in the development of a technic for reflection work in steeply folded or faulted regions.

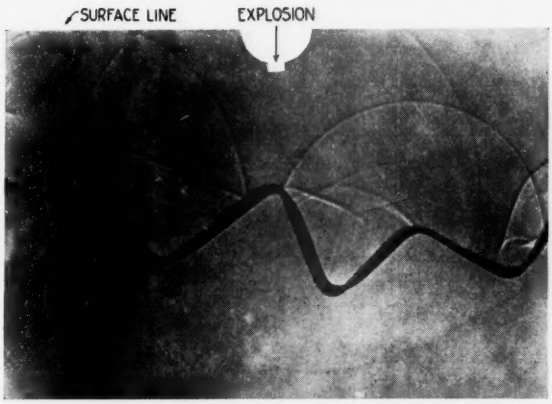


FIG. 14

First, not all returned waves may be treated as simple reflections whose places of origin are to be plotted by geometrical means as portions of strata. Diffracted waves, and waves returned by non-stratified causes can play a large and significant part in the total wave pattern received in such regions.

Second, such structural conditions must necessarily return many groups of waves from different directions, but with simultaneous or overlapping arrivals. Any attempt to map such regions must successfully receive and define the returned waves. If any wave is lost, the thing in the earth which originated it will also be lost from the picture. As a specific instance, there are many places where a succession of sedimentary beds exists, none of which give outstanding or distinctive reflections which permit them to be used as markers. If a normal fault occurs in such a region, we cannot hope to detect its

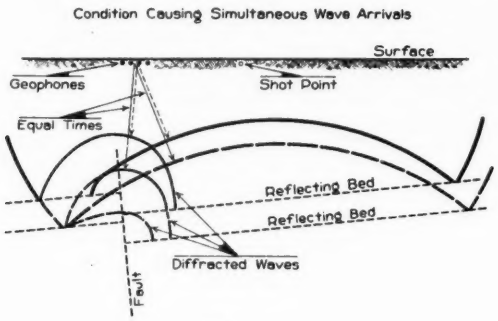


FIG. 15

presence satisfactorily by correlation, since the interval pattern between successive reflections on one side of the fault will very frequently resemble that on the other side to a sufficient degree, regardless of possible vertical displacements between the patterns, so that no definite proof of faulting may be obtained by correlation.

Likewise, normal faulting may often occur in such regions without producing a marked change in attitude between the beds on one side and the beds on the other side of the fault.

In such cases, the only means left by which such a fault might be detected would seem to lie in the detection and identification of diffracted waves originating from discontinuities in the successive strata where they reached the fault.

Fig. 15 shows such a region and is patterned after the model photographed on Fig. 6. The position of the receivers in Fig. 15 has been so chosen that reflected waves from two successive reflecting beds will arrive from one direction, while diffracted waves from two successive discontinuities in a fault will arrive from a definitely different direction. In order to separate and identify both of these sets of waves, the receiving apparatus must obviously be capable of angu-

lar discrimination—that is, it must be able to favor waves arriving from any chosen direction, and at the same time suppress waves arriving from other undesired directions.

Conditions where a number of different waves are traveling simultaneously in the same medium, but may be separated and identified, are common in the modern technical world. Telephone conversations, for example, are conducted through the same copper wire which serves for a number of other two-way conversations at the same time. And the ether carries, any hour of the day, a far greater miscellany of criss-cross vibrations, each of which may be separated from the total group and separately used.

It will be noted that, if we were to attach an oscillograph to a telephone wire which was carrying a number of conversations at one time, the wave record from the oscillograph would be undecipherable. Even though we knew the precise appearance of the waves, for, say, the vowel *a*, we would look in vain on our oscillograph records for such a group unless, by sheer accident, everyone else had happened to be silent while one conversing party said *a*.

Similarly, a radio set without tuning would receive from the ether so many interlocking sounds that the ear would be unable to identify any of them separately. However, the confusion in an oscillograph record connected to a multi-party telephone conversation does not indicate that these waves are inseparable. It merely indicates that they cannot be separated by an oscillograph, and that some other means must be used.

Correspondingly, if we find in the earth good evidence that wave groups are arriving simultaneously from various directions, and if a visual record of the commonly used type becomes so confused in such regions as to be unreadable, this does not necessarily mean that the individual waves in the earth cannot be separately identified. It merely means that we cannot conveniently separate them by the use of a simple visual record.

Where waves are traveling in a common medium, and we desire to separate them at a receiving point, it is necessary that the wave to be separated differ, in some one of its properties, from all of the other waves. In the case of the telephone conversations, each conversation is sent as a modulated carrier wave having a definite and very high frequency. Electrical tuning can, therefore, be used, and set to respond to any desired carrier wave, thereby releasing only that speech which has been consigned to that particular carrier. Similarly, the carrier

waves in the ether have different, tunable, vibratory frequencies by which any one may be selected, and the subject or message consigned to that frequency may be separated and identified.

Wave groups returned from the earth, as a result of a downgoing wave from an explosion, do not differ materially in frequency. Hence, they cannot be tuned in or out individually. If they are to be separated at all, some other property than frequency must be used.

Fortunately, these arriving wave groups differ in one other property, which is precisely the one in which we are interested—namely, direction of arrival. Accordingly, if a directionally sensitive receiving means could be devised, it would be possible to separate and identify waves reaching the receiver with various directional properties.

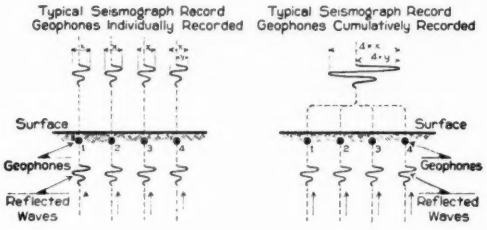


FIG. 16

A means for conferring directional properties on receiving systems has been known for some time, and consists in the so-called "grouped geophone" arrangement. This is shown diagrammatically on Fig. 16. On the left side of the plate, four individual geophones are shown, and it is assumed that they are being acted upon by a vertically arriving wave. For the purposes of the diagram, this arriving wave is shown as four individual arriving elements, one under each geophone. Further, and solely for the purposes of convenient diagramming, the waves are indicated as vibrations transverse to the direction of propagation. Above the geophones, waves are indicated whose amplitudes correspond to the electrical energy traveling from the geophone along the cable to the recording system.

To the right of the picture these four geophones are shown acted upon by a similar wave front, but having their outputs connected to a common circuit which correspondingly contains an electrical impulse with four times the energy of that produced by any individual geophone.

Such a group of geophones has distinct directional properties, as

clearly shown in Fig. 17. To the left of the plate four such groups of geophones are shown, each group feeding into its own electrical circuit. When such an arrangement is used in the field, each group is made to produce a single trace on the ultimately recorded record. To the right of Fig. 17 is shown a single such group when acted on

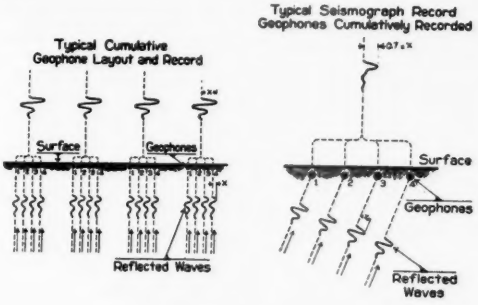


FIG. 17

by a wave which is arriving from a non-vertical direction. It will be readily seen that the wave elements do not reach the geophones 1, 2, 3 and 4 at identical times. Hence, they will not be added together to produce four times the energy, as was the case on the preceding plate. Instead, the outputs of the several geophones will conflict with each

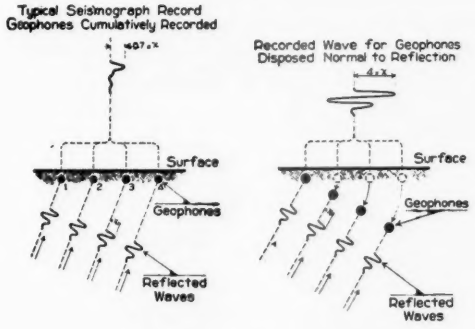


FIG. 18

other, and an electrical impulse somewhat of the form shown in the diagram will be sent out when this group of geophones is acted on by such a non-vertical wave.

Fig. 18 indicates one manner in which a group of four geophones could be made to give a good response to a non-vertical wave. To the left of the plate, for purposes of comparison, one of the preceding dia-

grams has been repeated, showing that the ordinary arrangement of four geophones connected in a group give relatively poor response to a non-vertical wave direction.

At the right of the plate it is shown that if these geophones could be moved from their former positions at the surface and planted instead at successively increasing depths, a position could be found for them at which they would once more receive the arriving wave elements simultaneously.

Under such conditions, their cumulative output would again contain four times the amount of energy available from each individual geophone.

As a practical matter, therefore, if we knew in advance the direction from which an arriving wave was expected, we could hope to plant a group of geophones at successively increasing depths, and connect them to any circuit, in such manner as to accentuate any reflected waves arriving from this predetermined direction. Under such conditions, however, there would be little point in making the experiment, since the answer would be already known.

If we were to attempt to conduct exploration in an unknown territory using this method, it would be necessary to plant each group of geophones in some definite relation of increasing depth, and then to fire a shot and record whatever waves might be arriving from this direction. Thereafter, all the geophones could be replanted to favor some new direction, and another shot fired to determine what reflections, if any, might be arriving from the new direction.

As a practical field procedure such a method is obviously ridiculous, on account of the large number of placements and shots required for each position. The diagram has been given merely to illustrate the fact that a group of geophones placed horizontally constitute a means of selectively receiving waves from one direction—but that, by placing the geophones other than horizontally, waves from any other chosen direction could be selectively received.

The system devised by the author involves the ability to examine any complex group of waves arriving from different directions and to select from this group and emphasize waves from any chosen direction, suppressing those from other directions. This is not done during the original recording, however, but subsequently by making the original record as a sound track film, which can be passed through an analyzer whose optical and electrical elements resolve the complex vibration into its various directional elements. This method permits

the directions of all the various waves to be determined from a single shot in the field.

A difficulty commonly experienced when grouped geophones are used, in an attempt to confer directional properties on a system, lies in the fact that the low velocity or weathered surface layer of the earth may not have uniform thickness or properties under the successive geophones.

Fig. 19 illustrates such a condition. At the left of the plate a uniform surface layer is shown, through which the reflected group of waves may pass without altering the time of arrival of each wave element at the respective geophones. Under such conditions good cumu-

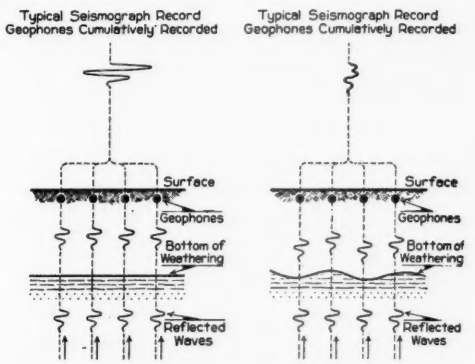


FIG. 19

lation of the outputs of the individual geophones will result and the equipment will operate satisfactorily as a means for selectively increasing the amplitude of vertically arriving waves.

On the right of Fig. 19 is shown the condition resulting from an irregular weathered layer. It will be observed that the elements of reflected waves arrive below the weathered layer at identical times, but that, after passing into the weathered layer, these wave elements reach the geophones at non-identical times and hence tend to interfere with each other and partially cancel the cumulative effect which would otherwise have been obtained. Under such conditions the cumulative output of the four geophones in the group will resemble that shown above them. Comparing this cumulation with the preferred one shown at the left of the plate, it will be seen that an irregular weathered layer may almost entirely destroy any advantage obtained by grouping geophones.

By observing individual times of arrival of reflected waves on these geophones, however, this irregularity in surface layer conditions may be detected and evaluated. Thereafter, in the author's equipment, such irregularities can be compensated for by appropriate adjustments of the analyzing apparatus. As a matter of possible interest, some of the equipment for the new system[4] is shown herewith. Fig. 20 pictures the recording truck for a ten track wave recording unit. Cable reels are protected as shown by a folding cover as a convenient means of

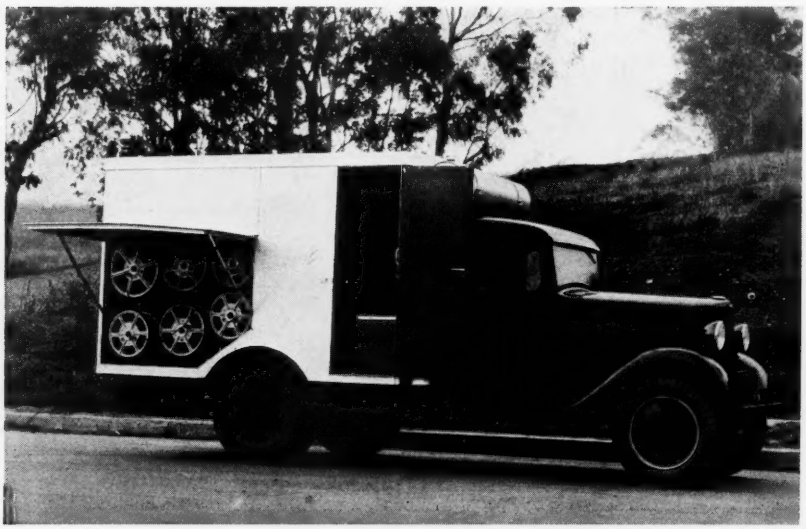


FIG. 20

avoiding moisture trouble and otherwise providing against theft or tampering. The water supply for film washing is contained in the tank over the cab. The ice box, visible through the opened operating compartment door, contains ice for controlling developer temperature when needed, and also serves as a seat for the operator. The operator's compartment is heat insulated, and means are provided for circulating the air in the compartment past the ice chamber when desired on account of hot weather.

Fig. 21 shows the interior of the operating compartment in the recording truck. At the upper left of the picture is a terminal and switch panel box where all battery circuits are controlled, fused,

[3] This new technic has been termed controlled directional selectivity, and is designated, for the sake of brevity, as the C. D. S. method.

switched and measured. A volt meter with a percentage scale and selector switches permits the measurement of any battery voltage at will with the same meter.

At the upper center of Fig. 21 are seen the ten amplifier units, and below them gain control and other adjustments, while individual volume level indicators for the ten channels are shown at the bottom of the instrument channel. At the right of the plate the film drying rack can be seen.

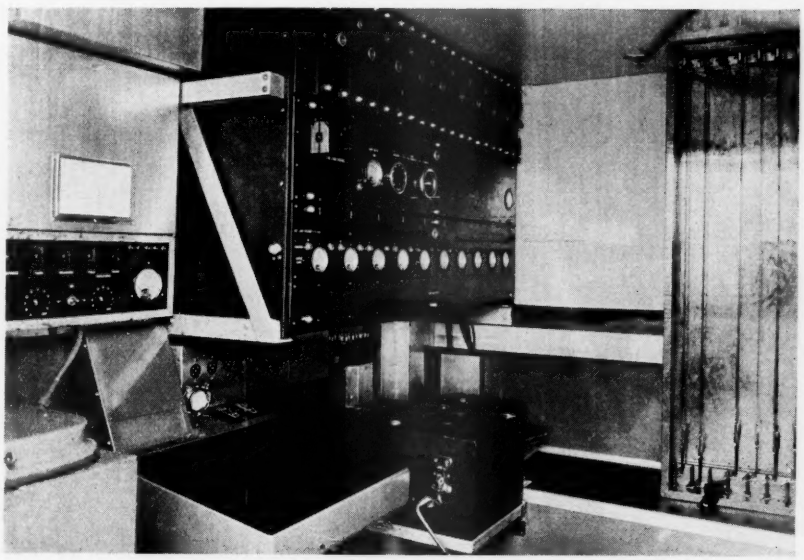


FIG. 21

At the lower left of the plate is the film developing and fixing tank with its water tight top closed down. This tank is heat insulated and thermally ballasted with a large amount of wash water which may be either heated or iced. Temperature control within 2° is thus readily possible, and this accuracy is more than sufficient to permit maintenance of good photographic quality in the sound tracks. Immediately to the right of the developer tank is a small illuminated glass slide on which film may be inspected. Farther to the right is the operator's desk, under the top of which record books and the like may be kept. To the right of the desk is the recorder proper, driven by a governed spring motor. It may be loaded by opening the hinged top, the operating compartment being light proof when the outer door is closed.

Fig. 22 shows the automatic optical analyzer which combines the records of the ten sound tracks on any one film to produce a sequence of analyzed components, each pertaining to a definite direction of arrival in space.

The magnetic drive for the analyzer pen is shown at the upper left of the illustration, and is mounted on tracks permitting it to occupy

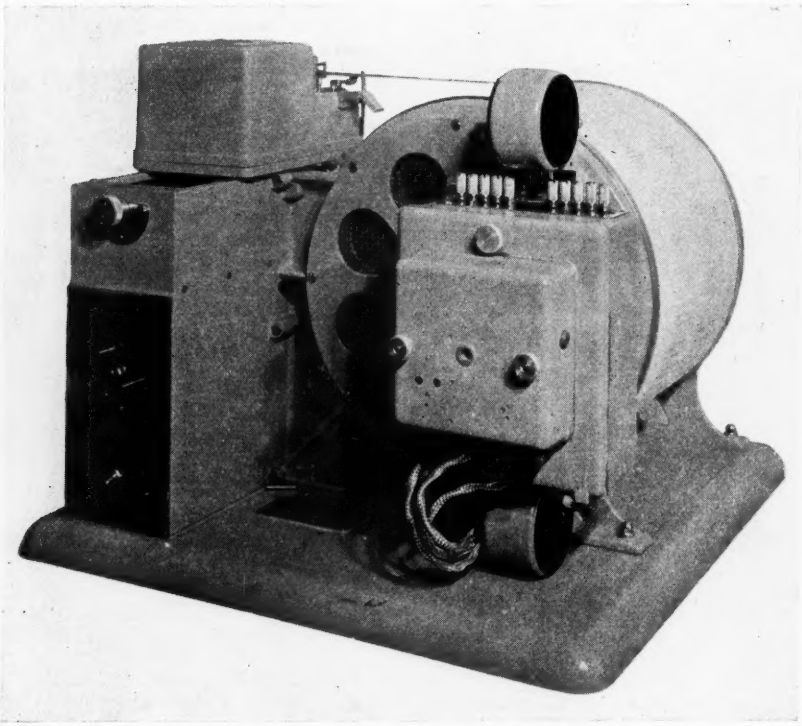


FIG. 22

successively a number of predetermined positions, one for each successive repetition of the analyzing process. The large drum is rotated by motor contained within it, a paper strip serving to record the pen movements. Recorded waves can be clearly seen on this strip in the illustration, The film on which the analysis is being conducted passes from the small upper cylindrical container, shown in front of the drum, to a small lower cylinder, being driven by a sprocket contained within the analyzing mechanism. This sprocket automatically returns the film to the starting position at each revolution of the drum.

The optical elements of the analyzer are contained in the rectangular compartment in front of the main recording drum whose front is hinged so that it may be opened for inspection. The small control knobs on the top of the analyzer compartment serve to apply individual time corrections to compensate for irregular surface layers.

The amplifying and control equipment for the electrical circuits are shown at the left of the plate. The entire apparatus is driven from alternating current, the power supply source being mounted on a separate panel not shown in the illustration. This power supply source is

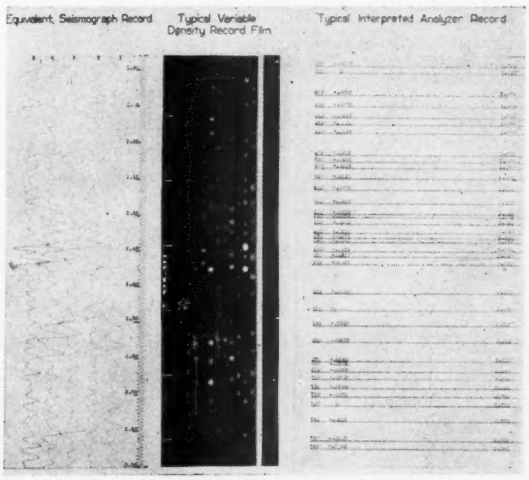


FIG. 23

compensated against line voltage changes, so that the amplitude of the pen record is at all times determined solely by the amplitude of the sound track record on the film.

Fig. 23 shows a variably density film, at the center of the plate, with a typical analyzer record as obtained from this film shown at the right of the plate. The transverse marks are put on by the person doing the interpreting, the designations on each line referring to the successive identified wave trains, giving for each a grade of dependability, and other quantitative factors from which the position in the structure of the point from which the wave was returned may be determined.

The central trace on the analyzer strip appears darker than the others. This is due to the fact that on the original strip the ink in the

pen is changed for this trace from blue to red, for convenience in identifying the successive traces. For comparison, this same sound track film has been reproduced at the left, not as an analyzer strip, but as a succession of individual waves such as are customarily recorded by other forms of reflection equipment. Repeated comparisons made in this manner have shown that records may be analyzed successfully in cases where the ordinary oscillograph form of record could not have been handled visually at all.

Fig. 24 shows a short section of an analyzer record, on which two reflections have been marked, arriving almost simultaneously but from different angular directions. Below the record is a diagram showing the reconstructed section of structure in which the sources of these two reflections have been plotted.

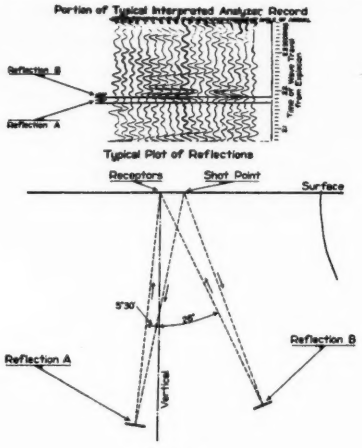


FIG. 24

In conclusion, the author desires to acknowledge his indebtedness to the members of his laboratory staff for their many valuable contributions to the development of the apparatus here described, and the technic for its use.

Particular credit is due to Mr. Curtis H. Johnson for working out the underlying mathematical factors involved in the analysis and plotting of complex structural conditions, and to Mr. B. F. McNamee and Mr. William T. Jochum for designing and supervising the construction of the recording and analyzing equipment. Acknowledgment is likewise made of the valuable services of Mr. E. M. Lane in developing a satisfactory and economical field operating technic for the new method.

RELATION BETWEEN FIRING CURRENT AND PERFORMANCE IN SEISMOGRAPH CAPS

L. A. BURROWS[1]

ABSTRACT

The time break characteristics of both "SS" and "SSS" seismograph caps are discussed. Particular attention is given to the occurrence, length, and uniformity of the various time breaks over a relatively extensive range of firing currents. At the higher firing currents, the "SSS" caps do not show the "induction period" characteristic of "SS" caps, and at the lower firing currents, the "total cap lag" of the "SSS" cap is less than that of the "SS." Thus the "bridge break" and the "total cap lag" of this newer product are not only shorter, but they are more uniform than those of the older product ("SS" caps).

Essentially, an electric blasting cap consists of a waterproof metal shell containing a pressed explosive charge or charges and a firing circuit. The pressed explosive load may be either a single charge or a base charge of a high velocity, high strength compound upon which is superimposed a primer whose function is to initiate detonation of the main explosive charge. The firing mechanism consists of a very fine bridge wire, connected across the two leg wires of the cap, and surrounded by an ignition composition which may be either a loose charge or a solid pellet formed around the bridge wire.

When sufficient current is applied to the cap to shoot it, one of two things may happen. The bridge wire may be fused through, followed within a short interval of time by the detonation of the cap, or detonation of the cap may precede the rupture of the bridge wire, in which case the detonation breaks the firing circuit. Since the velocity of detonation of the pressed explosive load is sufficiently great that the time required for the explosion to travel through this short column of material is negligible, the ignition composition surrounding the bridge wire and the firing current used determine whether bridge wire severance occurs before detonation or vice versa. These points will be referred to in greater detail later.

In establishing time versus distance values in seismograph exploration, it is essential that a record be made instantly of the dynamite explosion which initiates the seismic vibrations. The most commonly employed time-break system uses only one cap which has two functions; first, the detonation of the dynamite charge, and, second,

[1] Contribution No. 20, from the Eastern Laboratory of the E. I. du Pont de Nemours & Company, Gibbstown N. J.

the production of the desired time-break, The latter step is accomplished by making the firing circuit a part of the timing circuit, and using the breakage of the firing circuit as a time signal. When this method is used, it is imperative that the elapsed time from severance of bridge wire to detonation of the cap shall be either very uniform or negligible. The time from application of current to severance of the bridge wire is also of interest in some cases, and it should be as uniform as possible.

Another and less commonly employed time-break system[2] utilizes two electric blasting caps which are hooked in series. One of these caps detonates the dynamite charge, and the other is used to break a wire in the timing circuit. For satisfactory performance, this method requires that the time from application of current to detonation of the caps shall be practically constant. For the sake of clarity and uniformity, the time from application of current to bridge wire severance will hereinafter be designated simply as "bridge break"; the time from bridge break to detonation of the cap will be designated as the "induction period"; and the sum of these two will be called the "total cap lag."

The special requirements of high speed and uniformity of detonation necessitated the development of special caps for geophysical prospecting. Numerous designs of electric blasting caps, several different kinds of bridge wire, and an extensive series of explosive compounds were evaluated in the laboratory. The effect of firing amperage was also determined. Early in this investigation a combination of bridge wire and explosive charge was developed which was a material improvement over caps then in use for this type of shooting. As a result of this work, the "SS" seismograph cap was introduced to the trade in October, 1933.

The laboratory program was continued, after manufacture of this new cap was started, in order to produce the most satisfactory cap possible for geophysical prospecting. Several cap charges were developed which were far superior to the materials used in the "SS" seismograph cap. The most satisfactory of these new explosive compounds is being used in the manufacture of the "SSS" seismograph cap which has been on the market since April, 1935.

It might be well at this point to describe briefly the method used

[2] For a discussion of the various time-break systems see "Explosives for Geophysical Prospecting," G. H. Loving and G. H. Smith, *Journal of the Society of Petroleum Geophysicists*, *6*, 27–33 (1935).

for obtaining the various time-breaks characteristic of the caps studied. A cathode-ray oscillograph coupled with a one-thousand cycle oscillator provided the timing device. The primary or firing circuit was hooked to the leg wires of the cap, and a secondary circuit was passed around the base of the cap so that it was broken when the cap detonated. Both of these circuits were connected through a suitable

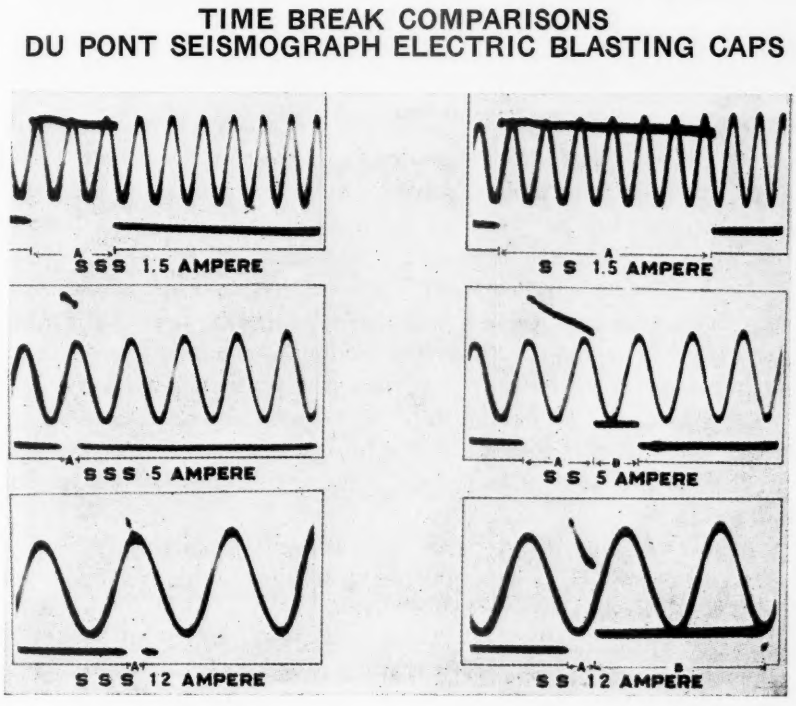

TIME BREAK COMPARISONS
DU PONT SEISMOGRAPH ELECTRIC BLASTING CAPS
S S S 1.5 AMPERE
S S 1.5 AMPERE
S S S .5 AMPERE
S S .5 AMPERE
S S S 1.2 AMPERE
S S 1.2 AMPERE

FIG. 1

amplifier to the horizontal plates of the oscillograph. Actual photographs of the time-break characteristics of both "SSS" and "SS" seismograph caps are shown in Fig. I.

Taking the picture obtained from a "SS" cap fired with 5 amperes as an example, these photographs may be explained as follows:

First of all, this is in reality two pictures, one of the time-breaks and the other of the thousand-cycle wave from the oscillator superimposed upon the first picture. When the oscillograph was turned on, the electron beam started at the lower left-hand corner of the picture and traveled in a straight line until current was applied simultane-

ously to the primary and secondary circuits, deflecting the beam sharply upward. The beam then traveled on across the screen in a slightly downward direction, showing decreasing potential, due to the increasing resistance of the heated bridge wire. When the bridge wire fused, the primary circuit was broken, causing a sharp decrease in potential between the horizontal plates with correspondingly sharp drop in the beam. The detonation of the cap and simultaneous rupture of the secondary circuit allowed the beam to fall to its starting level. The timing wave was then flashed across the screen at the same speed with which the beam had previously traveled.

In order to calculate the time-breaks, the distances "A" and "B" are divided by the distance from crest to crest of the timing wave. These two values are then divided by one thousand (thousand-cycle oscillator) to give the time in seconds required; "A" for "bridge break" and "B" for the "induction period."

The photograph from a "SS" cap shot with 12 amperes resembles the 5 ampere picture, the essential differences being that the "bridge break" is shorter and the "induction period" is somewhat longer. The 1.5 ampere picture of the "SS" cap, however, presents a striking difference. In it, it is noted that the only time-break present is the "bridge break." Simply, this means that the bridge wire is not fused through, but that both it and the secondary circuit are broken by the detonation of the cap.

An examination of the "SSS" photographs reveals that, like the 1.5 ampere "SS" shot, but unlike the "SS" shots at higher amperages, no "induction period" is present. The time required for "bridge break" in the "SSS" cap is also less than that required in the "SS" cap.

It might be well to point out here that the firing current specified actually passed through the bridge wire of the cap regardless of other resistances in the circuit or variations in the resistance of the caps caused by different length leg wires. This was made possible by balancing the resistance of the firing circuit against a dummy resistance, then carefully adjusting the firing current through the dummy resistance before firing the cap. In actual use of these caps, this would perhaps not be practical, but, knowing the resistance of the circuit and the voltage applied, the firing current can be easily obtained.

In Fig. 2, the time-breaks of both "SSS" and "SS" seismograph caps are plotted against firing current.

Considering the low amperage part of the curves first, it is seen that the slopes of both curves 1 and 2 are very steep up to a firing

current of about 1.5 amperes. In this region, a very slight variation in the current which reaches the cap will cause quite a large variation in the time required for the "bridge break." If the time signal is to be given at breakage of the firing circuit, this is relatively unimportant. However, if the time required for the "bridge break" is of interest, very constant firing currents must be used to obtain consistent results with either type cap at low amperages. Since the two curves are practically parallel in this region, the extreme variation of "bridge break"

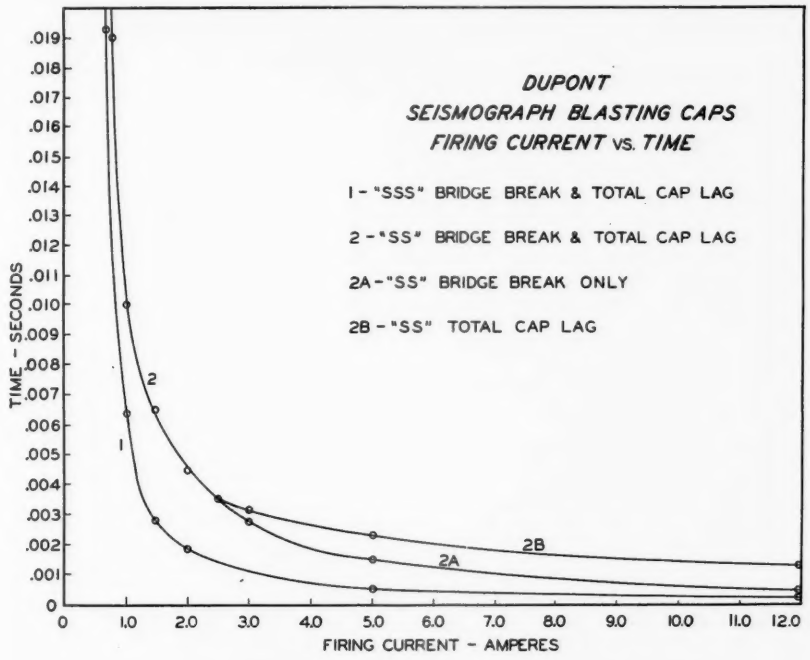


FIG. 2

with slight change of firing current is about the same in both "SSS" and "SS" caps.

In the region approaching the minimum firing current, the curves are practically vertical and can not, therefore, be shown upon a graph of this scale. The curves are, of course, discontinuous at the minimum firing current, which for the "SSS" cap is 0.45 ampere and for the "SS" cap is 0.35 ampere. Since this value for the "SSS" cap is the larger of the two, its curve will stop first. The "SS" curve will eventually meet the "SSS" curve, cross it, and continue on until failure occurs due to insufficient current.

Having a lower minimum firing current, the "SS" cap can be fired with currents which are too weak to detonate a "SSS" cap, but it is questionable whether or not one may safely depend upon extremely low currents in the firing circuit. Poor connections, low dielectric strength of the wires leading from the firing apparatus to the cap, broken insulation on the leg wires of the cap, and numerous other factors might readily cause sufficient current leakage to give a misfire. For perfectly safe practice, a minimum of one ampere should be allowed for any type of shot.

The slopes of both curves decrease rapidly above 1.5 amperes until a point is reached where the curves are almost flat. In the region above 5 amperes, a relatively large variation in the firing current employed has little effect upon the "bridge break." In fact, an increase in current from 5 to 12 amperes with a "SSS" cap only decreases the "bridge break" by approximately 0.0002 second, while in the low amperage portion of the curve an increase in current from 1.0 to 1.5 amperes decreases the "bridge break" by about 0.004 second.

Following the "SS" curve throughout its course, it is noted that this curve divides into two curves at approximately 2.5 amperes. Above this point, we have Curve 2a for "bridge break" and Curve 2b for "total cap lag." The vertical distance between the two curves at any point is the "induction period" at that firing current. This "induction period" increases with increasing amperage.

The "SSS" curve is a single curve throughout because no "induction period" develops even with high firing currents. The complete elimination of this highly undesirable characteristic from an electric blasting cap was made possible by the unique construction of the new "SSS" seismograph cap. This has not only eliminated an important source of error in time-break systems which employ the breakage of the firing circuit as a time signal, but it has also given a detonator which has a shorter, more uniform "bridge break" and, consequently, a shorter, more uniform "total cap lag."

The uniformity, as well as the length, of the time-breaks obtained with these caps is of interest. Typical series of shots with "SSS" caps are shown in Table I.

TABLE I

"Bridge Break" and "Total Cap Lag" of "SSS" Seismograph Caps

	1.5 amperes	*5.0 amperes*	*12.0 amperes*
	0.0028 sec.	0.00045 sec.	0.00020 sec.
	0.0029 "	0.00047 "	0.00022 "
	0.0027 "	0.00048 "	0.00020 "
	0.0027 "	0.00045 "	0.00021 "
	0.0028 "	0.00045 "	0.00021 "
Average	0.0028 sec.	0.00046 sec.	0.00021 sec.

It is worthy of note that the percentage variation in the "bridge break," which in this case is also the "total cap lag" of the "SSS" cap, is practically constant at all firing currents, but the actual variation at 1.5 amperes is 0.0002 second, while at 5 amperes it is 0.00003 second, and at 12 amperes it is only 0.00002 second.

Similar series of shots for "SS" caps are given in Table II.

TABLE II

TIME-BREAKS OF "SS" SEISMOGRAPH CAPS

Firing Current	*Bridge Break*	*Induction Period*	*Total Cap Lag*
1.5 amperes	0.0063 sec.	—	0.0063 sec.
" "	0.0064 "	—	0.0064 "
" "	0.0066 "	—	0.0066 "
" "	0.0069 "	—	0.0069 "
Average	0.0065 sec.		0.0065 sec.
5.0 amperes	0.00133 sec.	0.00147 sec.	0.00280 sec.
" "	0.00147 "	0.00080 "	0.00227 "
" "	0.00157 "	0.00075 "	0.00232 "
" "	0.00153 "	0.00034 "	0.00187 "
Average	0.00148 sec.	0.00084 sec.	0.00232 sec.
12.0 amperes	0.00037 sec.	0.00072 sec.	0.00109 sec.
" "	0.00036 "	0.00092 "	0.00128 "
" "	0.00038 "	0.00100 "	0.00138 "
" "	0.00038 "	0.00100 "	0.00138 "
Average	0.00037 sec.	0.00091 sec.	0.00128 sec.

The total variation in the "bridge break" of these caps is somewhat greater than that of "SSS" detonators, being 0.0006 second at 1.5 amperes, 0.00024 second at 5 amperes, and 0.00002 second at 12 amperes.

When the "total cap lag" of the "SS" cap is compared with that of the "SSS" cap, another factor enters in; namely, the "induction period." This "induction period" makes up quite a large part of the "total cap lag" of the "SS" cap at higher amperages, and an examination of Table II shows that this lag is much more erratic than the "bridge break." Consequently, the "total cap lag" of the "SS" cap is only slightly more uniform at high amperages than it is at low amperages, in spite of the fact that it decreases with increasing current. The variation in the "total cap lag" of the "SSS" cap remains the same as that of the "bridge break," but the variation in the "total cap lag" of the "SS" cap becomes 0.0006 second at 1.5 amperes, 0.00093 second at 5 amperes, and 0.00029 second at 12 amperes.

These two tables illustrate quite clearly the superiority of the "SSS" over the "SS" cap. The "bridge break" and "total cap lag" of

the former detonator are not only shorter than those of the "SS," but they are more uniform. This is due to the fact that the bridge wire of the "SSS" cap is always broken by the explosion of the base charge, while the bridge wire of the "SS" cap is broken by the explosion of the detonator at low amperages, and fused through before detonation at higher firing currents.

In view of these facts, it is readily seen that, regardless of the time-break system employed, the "SSS" cap is more satisfactory than the "SS" cap, unless very low firing currents are used. The dangers involved in the use of extremely low currents have been discussed, but they can not be stressed too strongly. Misfires can and do occur with all kinds of electric blasting caps when low firing currents are employed. These misfires are expensive, and experience has shown that they are hazardous.

It has often been considered necessary to use low firing currents in systems which use the breakage of the firing circuit as a time signal in order to avoid an "induction period" in the detonators used. Since the "SSS" cap has no "induction period," higher firing currents can be used without causing the slightest variation in the time signal, and the chance of having misfires can be materially decreased. When the "bridge break" is of interest, and when the uniformity of the "total cap lag" is an important factor, the advantages of the "SSS" over the "SS" cap, and the advantages of using high firing currents, are quite apparent.

SUMMARY

The time-breaks obtained with an electric blasting cap depend upon the composition of the cap and upon the firing current used. At low firing currents there is an extreme variation in the "bridge break" with slight changes in amperage, but at relatively high firing currents this variation is much less pronounced.

Due to its lower minimum firing current, the "SS" seismograph cap can be fired with amperages which will not detonate a "SSS" cap, but the use of such low firing currents is not good practice. The minimum firing current recommended for shooting any type of detonator is 1.0 ampere.

In time-break systems which employ the breakage of the firing circuit as the time signal, the "SS" seismograph cap will give satisfactory results at low amperages, but with currents above 2.5 amperes an "induction period" occurs in this detonator. This "induction period" increases with increasing firing current, and it is much more erratic than

is the "bridge break." This undesirable feature of the "SS" cap, or any cap of its type, makes it unsatisfactory for this kind of shooting with relatively high firing currents. Since the bridge wire of the "SSS" cap is always broken by the explosion of the detonator regardless of the firing current used, it has no "induction period," and will, therefore, give excellent results in this time-break system with any current which is safely above its minimum firing current.

Provided sufficiently high firing currents are used to avoid the danger of misfires, the "SSS" seismograph cap has a shorter, more uniform, "bridge break" and "total cap lag" than does the "SS." Consequently, the "SSS" detonator is much more satisfactory for use in any time-break system where these time lags are factors of importance than is the "SS." The higher the firing current used with the "SSS" cap, the shorter and more uniform will be the "bridge break" and "total cap lag."

EXPLOSIVES FOR SEISMIC PROSPECTING

N. G. JOHNSON AND G. H. SMITH*

ABSTRACT

A test has been devised whereby explosives can be graded visually according to their relative merit for blasting under high water pressures. Representative explosives for seismic prospecting are compared and analyzed by means of this test. One of the newest developments in explosives for deep-hole shooting is described, and its superiority for this work is clearly demonstrated.

The function of explosives in seismic prospecting is too well known to require detailed discussion in this paper. It is sufficient to state that the reflection method, which is in most general use at the present time, requires primarily that the explosive be sufficiently water-resistant to deliver full efficiency under depths of water up to 250 feet. An additional important requirement, in certain types of reflection shooting, is that the explosive must be hard-packed and in a rigid container, so that it may be pushed down partially blocked drill-holes.

Standard grades of dynamite are seldom used in depths of water over 50 feet, such use comprising the deepening of rivers and harbors, etc. The explosives industry was, therefore, placed at a serious disadvantage when the geophysical prospector demanded explosives which would perform consistently in depths up to 250 feet. Naturally, those grades known to be satisfactory for the usual type of submarine blasting were first recommended. These were soon modified to meet certain specific requirements of reflection shooting, that is, they were packed more firmly than usual and were provided with special, extra-heavy, wrappers. On the whole, these explosives have been very successful. There have, however, been certain instances where it appeared that full efficiency was not being developed. Efforts to clarify these situations led to extensive investigations in the field, including carefully supervised comparisons in actual seismic prospecting. These data were very difficult to interpret, however, because of the many variables inherent in seismic work. It was then decided that an effort should be made to develop a test which would classify the various explosives according to their relative merit for use under high water pressures, independent of variables other than the explosives themselves. Such a test has been developed, and it is the purpose of this article to describe the work and to discuss the results obtained.

* Contribution No. 19 from Eastern Laboratory, E. I. du Pont de Nemours & Company.

TYPES OF EXPLOSIVES USED FOR SEISMIC PROSPECTING

According to the usual practice in the industry, the du Pont Co. has adopted trade names for the several types of dynamites offered to the seismic prospecting group. Before going further, it is believed desirable to trace briefly the development of the standard grades, and to define the seismograph types in terms of the latter.

It is generally known that Nobel perfected the commercial manufacture of nitroglycerin, and made its use as a blasting agent practical by his invention of dynamite. In the broad sense, the term "dynamite" now covers any high explosive used for commercial blasting, and thus may include explosives containing no nitroglycerin. Nobel's dynamite, however, comprised high percentages of nitroglycerin mixed with various absorptive materials. Such powders are known today as the "Straight dynamites" and contain nitroglycerin in an amount equal to their grade strength markings. The higher grades, such as 60%, are quite water resistant but are unsuited for seismic prospecting because of their relatively high sensitiveness to shock and friction.

Some years after his invention of dynamite, Nobel discovered that certain types of nitrocotton were soluble in nitroglycerin, producing a gelatin. His first commercial utilization of this discovery was the production of "Blasting gelatin," the composition of which is 91% nitroglycerin, 8% nitrocotton, and 1% chalk. This is a tough, rubbery material resembling an "Artgum" eraser. Since Blasting gelatin is expensive, and unnecessarily strong for most purposes, it was soon diluted with materials such as wood pulp and sodium nitrate, to form a series of explosives which are now generally known as the "Straight gelatins." To reduce cost further, there was developed an additional series of gelatins, in which ammonium nitrate replaced a portion of the nitroglycerin. These, usually termed the "Special" or "Ammonia" gelatins, are equal in strength to the corresponding Straight gelatins, but are somewhat lower in velocity (rate of detonation) and less water resistant.

At the present time, the explosive in most general use for seismic prospecting is 60% Special (Ammonia) gelatin. While almost all explosives manufacturers offer this grade, each has prepared modifications especially for the geophysical trade. Du Pont "Seismogels A and B" are both in this category, grade A being packed very hard and grade B medium hard. Both are cartridged in extra-heavy containers.

As mentioned previously, the Straight gelatins contain more nitro-

glycerin than the Special gelatins and are consequently more water resistant and higher in velocity. A peculiarity of gelatin dynamites, however, is that they have two velocities, a low of around 8,200 feet per second and highs ranging from 13,000 to 20,000 or more depending upon the explosive content of the grade involved. Development of high velocity usually does not occur in the open, but will ordinarily result under close confinement in a drill-hole. High pressure, especially when due to water, greatly reduces the tendency of gelatin dynamites to assume their high velocities. Thorough investigation of the above facts led to development of the du Pont "Hi-Velocity" gelatins. These are essentially the same as the corresponding grades of Straight gelatin, but because of a patented feature may be relied upon to develop maximum velocity under all conditions of confinement or pressure. To a certain extent, the name "Hi-Velocity" may be misleading, in that the normal velocities are no higher than those of the corresponding Straight gelatins. The point is that the "Hi-Velocity" gelatins will give full efficiency under conditions which will cause inferior results in any other type of commercial explosive. Proof of this contention is offered by the data presented in the following paragraphs.

TESTS AT HIGH WATER PRESSURES

It is obviously both difficult and expensive to carry out tests on large quantities of explosives under heavy confinement. For one thing, such work must be carried out in a large bomb-proof, or in some isolated locality where damage would be unlikely to result. Consequently, it has been the general practice to expose relatively small quantities at the desired water pressures, and to remove the explosive from the pressure vessel before attempting detonation. These tests have the weaknesses, first, that the explosive is not tested under actual working conditions and, second, that little information is obtained as to the efficiency of the shot.

In the present work, it was first proposed that the explosives to be investigated should be shot, under water pressure, in a heavy steel pipe standing upright on a lead or aluminum plate. Such a test would show: (1) whether the detonation propagated from cartridge to cartridge throughout the column of explosive, and (2) whether the explosion took place at high or at low velocity. Preliminary experiments along these lines are illustrated in Fig. 1.

After preliminary trial, it was decided to use aluminum plates. These were $\frac{1}{2}''$ thick and $24''$ square. The pipe was "extra-heavy"

steel, of 2″ inside diameter for $1\frac{1}{4}$″ diameter powder, and of 3″ inside diameter for 2″ diameter powder. Four cartridges 8″ in length were used for each test, an electric blasting cap being placed in the last, or top cartridge in the pipe. The cap wires were led out through rubber gaskets between the flanges. All of these tests were carried out at 100 lbs. per sq.in. water pressure, which is equivalent to a depth of 231 feet. Approximately 15 minutes were required to apply pressure, transport the assembly to the shooting grounds, and return for the shot.

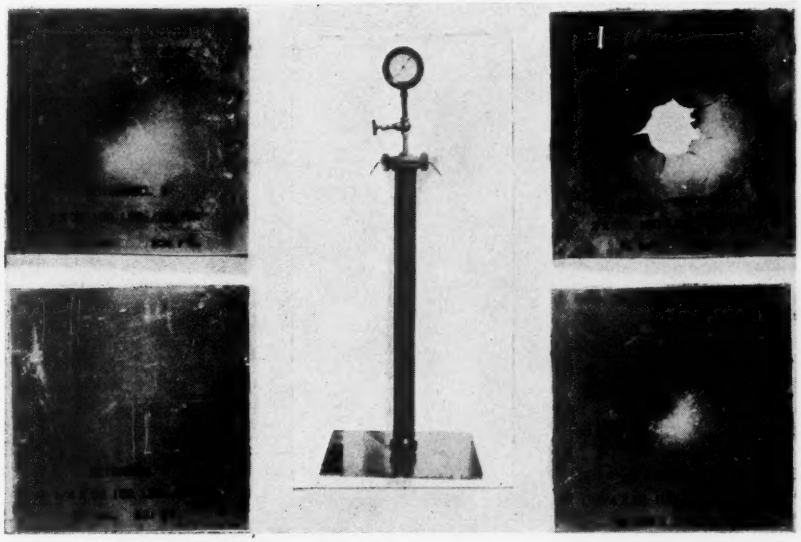


FIG. 1. Preliminary aluminum plate tests

Discussing Fig. 1, it will be seen that 60% "Hi-Velocity," in the 2″ diameter, propagated throughout the four cartridges. That the detonation took place at extremely high velocity is evidenced by the 6″ diameter hole in the aluminum plate. Reduction in the diameter of this grade to $1\frac{1}{4}$″ also resulted in complete detonation. Since only a small depression was found on the plate, it was apparent that high velocity had not been attained. The same type of plate was obtained with "Seismogel B" in the 2″ diameter. When "Seismogel B" was reduced to $1\frac{1}{4}$″, however, only the first, or "primed" cartridge detonated, the remaining three cartridges being recovered after the shot. Naturally, the plate corresponding to this test showed no mark. This pre-

liminary work brings out two points; namely, the superiority of 60% "Hi-Velocity" over "Seismogel B," and the advantage of the large over the small diameter.

After the experiments with aluminum plates, it was suggested that more intelligible results would be obtained by laying the pipe flat over lead cylinders spaced evenly down the length of the powder column. For example, such an arrangement would show definitely whether velocity tended to increase or decrease as the detonation wave progressed from cartridge to cartridge. As finally adopted, the lead block assembly is shown in Fig. 2.

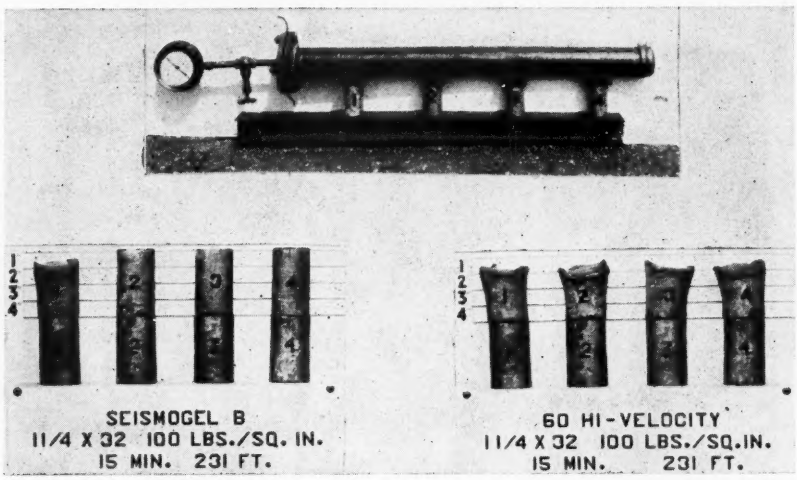


FIG. 2. Preliminary lead block compression tests

To obtain compression, rather than shattering, the blocks were placed between a steel rail at the bottom and $1'' \times 3'' \times 3''$ steel plates at the top. Lead block No. 1 rested directly under the first, or "primed" cartridge, while block No. 4 was directly below the last cartridge. These "blocks" were actually cylinders, $2\frac{1}{2}''$ in diameter and $4''$ in height, weighing approximately 10 lbs. each.

Results of preliminary lead block tests are also shown in Fig. 2. Confirming the aluminum plate tests, 60% "Hi-Velocity" gave complete propagation at low velocity, in the $1\frac{1}{4}''$ diameter at 100 lbs. per sq.in. water pressure. Similarly, "Seismogel B," under the same conditions, showed low velocity detonation of the first cartridge, with failure of propagation to the remaining cartridges.

Before going on to discuss the complete lead block tests, it is thought desirable to mention a few points which apply to all such tests. In the first place, the powders tested were of the standard "seismograph" type, of the proper consistency, and wrapped in the usual extra-heavy paper containers. Because the 2″ diameter is common in seismic prospecting, the bulk of the remaining tests were made in that diameter, the charge comprising three 2″×14″ cartridges. Under certain conditions exceedingly high velocities were obtained, re-

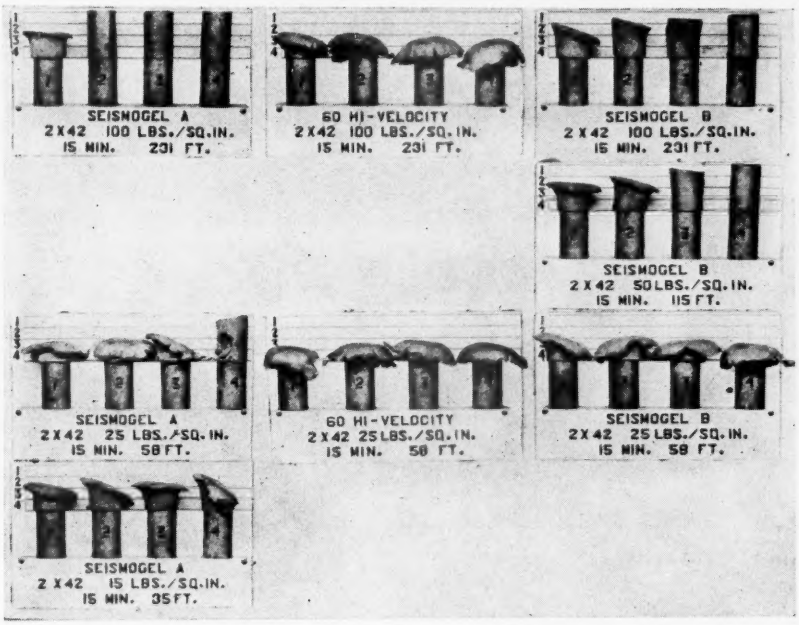


FIG. 3. Water pressure tests

sulting in extreme flattening of the lead blocks. To provide uniform comparison, therefore, all blocks were photographed resting upon similar uncompressed blocks. Anticipating a question as to why some blocks were compressed in a slanting direction, while others were mashed flat, it might be stated that no regularity was noted as to the presence, absence, or direction of these slants. Apparently they are a result of small differences in the position of the blocks under the explosive.

Fig. 3 presents data on the du Pont explosives most commonly used in seismic prospecting; namely, "Seismogel A," "Seismogel B,"

and 60% "Hi-Velocity." It will be noted that "Seismogel A" stands out as the poorest of the three powders. This grade failed to propagate at either 100 lbs. per sq.in. (231 feet) or 25 lbs. per sq.in. (58 feet). Complete propagation was obtained at good velocity, however, under 15 lbs. per sq.in. pressure (35 feet). It is evident that "Seismogel B" is superior to "Seismogel A" since, although "Seismogel B" failed to propagate completely at either 100 lbs. (231 feet) or 50 lbs. (115 feet) in the 2" diameter, it gave excellent results at 25 lbs. (58 feet). Data on 60% "Hi-Velocity" are also given in Fig. 3. A glance will show that the performance of this grade is outstandingly superior to either of the others.

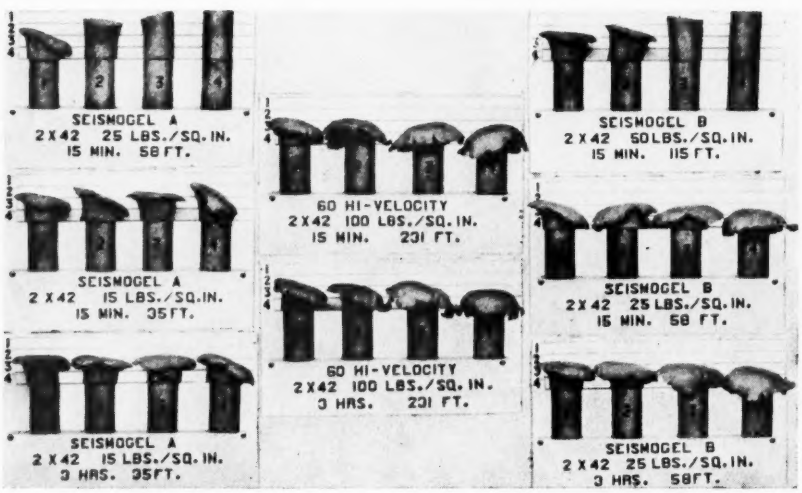

SEISMOGEL A
2 X 42 25 LBS./SQ. IN.
15 MIN. 58 FT.
60 HI-VELOCITY
2 X 42 100 LBS./SQ. IN.
15 MIN. 231 FT.
SEISMOGEL B
2 X 42 50 LBS./SQ. IN.
15 MIN. 115 FT.
SEISMOGEL A
2 X 42 15 LBS./SQ. IN.
15 MIN. 35 FT.
SEISMOGEL B
2 X 42 25 LBS./SQ. IN.
15 MIN. 58 FT.
60 HI-VELOCITY
2 X 42 100 LBS./SQ. IN.
3 HRS. 231 FT.
SEISMOGEL A
2 X 42 15 LBS./SQ. IN.
3 HRS. 35 FT.
SEISMOGEL B
2 X 42 25 LBS./SQ. IN.
3 HRS. 58 FT.

FIG. 4. Water pressure tests-effect of exposure

A few tests were made to develop the effect of exposure at a given pressure. These are shown in Fig. 4. In the case of "Seismogels A & B," the top photographs represent the lowest pressures used at which failure resulted. For example, "Seismogel A" failed to propagate completely at 25 lbs. per sq.in., but gave good results at 15 lbs. per sq.in. Three hours exposure at the latter pressure resulted in no deterioration. With "Seismogel B," failure resulted at 50 lbs. per sq.in. At the next lower pressure tried, that is, 25 lbs. per sq.in., results were excellent. In this case also, there was no deterioration after three hours' exposure. No shots were made beyond 100 lbs. per sq.in., at which point 60% "Hi-Velocity" showed maximum performance. No

deterioration whatsoever was noted at this pressure after three hours exposure. Indications are, from this work, that gelatins are subject to a "critical" pressure and that, below this pressure, the time of exposure is a relatively minor factor. In spite of this indication, however, good practice requires that the explosive be fired as soon after loading as is possible.

As has been mentioned previously, the reflection method frequently requires that several shots be made in the same drill-hole. Thus rigid explosives are of advantage in that they may be more easily pushed down holes which have been partially blocked as a result of previous shots. With this in mind, 60% "Hi-Velocity" gelatin

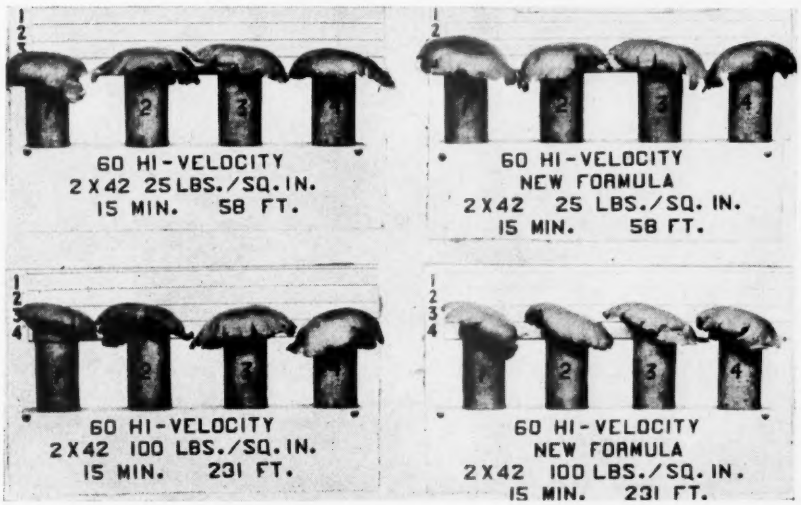


FIG. 5. Comparison of regular and seismograph 60% "Hi-Velocity" gelatin

was modified to produce the stiffest possible product, especially for use in seismic prospecting. This modification, designated "new formula," is shown in Fig. 5, in comparison with the softer form of 60% "Hi-Velocity" which is used in ordinary submarine blasting. It will be noted that the modification for seismic prospecting is fully as efficient as the older type.

Mention was made, in discussing Fig. 1, that increase in the diameter of the explosive resulted in improved performance. Additional work was carried out to amplify this point, the complete data being shown in Fig. 6. It is evident that the largest practicable diameter should be used.

In tracing the development of the various types of gelatin, the statement was made that "Seismogels A & B" were merely modifications of standard 60% Special (Ammonia) gelatin. Fig. 7 shows a

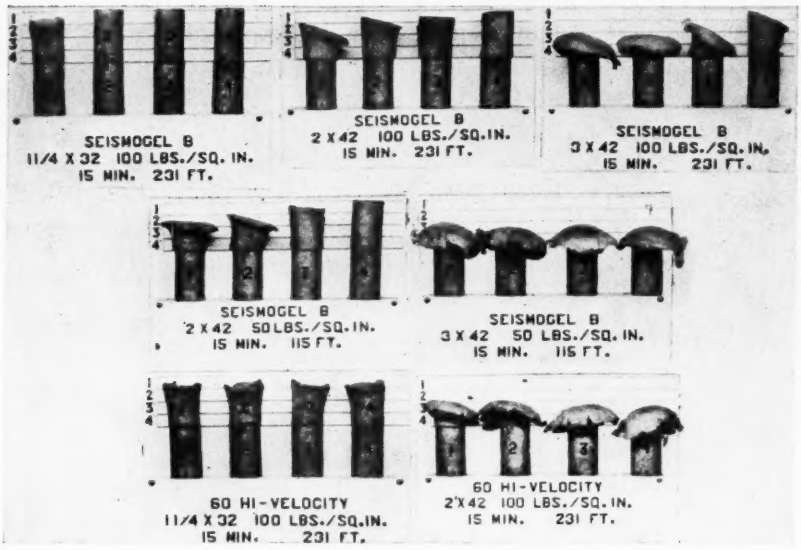

SEISMOGEL B
1 1/4 X 32 100 LBS./SQ. IN.
15 MIN. 231 FT.
SEISMOGEL B
2 X 42 100 LBS./SQ.IN.
15 MIN. 231 FT.
SEISMOGEL B
3 X 42 100 LBS./SQ. IN.
15 MIN. 231 FT.
SEISMOGEL B
2 X 42 50 LBS./SQ. IN.
15 MIN. 115 FT.
SEISMOGEL B
3 X 42 50 LBS./SQ. IN.
15 MIN. 115 FT.
60 HI-VELOCITY
1 1/4 X 32 100 LBS./SQ.IN.
15 MIN. 231 FT.
60 HI-VELOCITY
2 X 42 100 LBS./SQ. IN.
15 MIN. 231 FT.

FIG. 6. Effect of variation in diameter on performance of explosive

comparison of these grades. It will be seen that "Seismogel B" gave virtually the same results, while "Seismogel A" proved somewhat inferior.

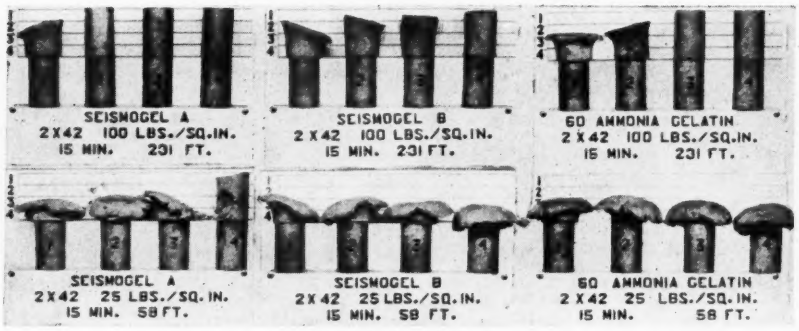


FIG. 7. Comparison of 60% Ammonia gelatin and the "Seismogels"

Again, it was stated that "Hi-Velocity" gelatins were the same as the Straight gelatins, with the exception of the patented low density

feature. Fig. 8 shows a comparison of the two 60% grades. The advantage of "Hi-Velocity" over Straight gelatin is particularly apparent in the tests at 100 lbs. per sq.in. (231 feet). Data on 80%

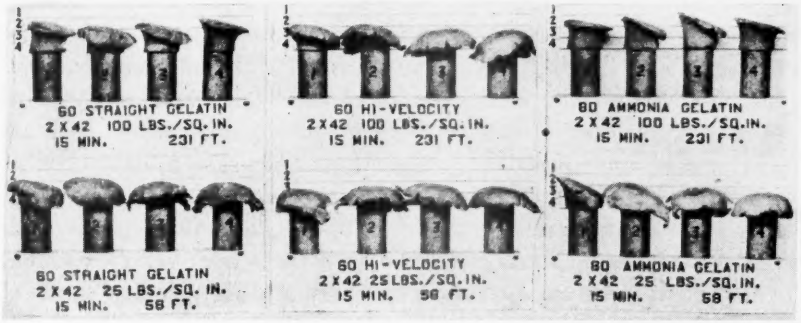

60 STRAIGHT GELATIN
2 X 42 100 LBS./SQ. IN.
15 MIN. 231 FT.
60 HI-VELOCITY
2 X 42 100 LBS./SQ. IN.
15 MIN. 231 FT.
80 AMMONIA GELATIN
2 X 42 100 LBS./SQ. IN.
15 MIN. 231 FT.
60 STRAIGHT GELATIN
2 X 42 25 LBS./SQ. IN.
15 MIN. 58 FT.
60 HI-VELOCITY
2 X 42 25 LBS./SQ. IN.
15 MIN. 58 FT.
80 AMMONIA GELATIN
2 X 42 25 LBS./SQ. IN.
15 MIN. 58 FT.

FIG. 8. Comparison of 60% Straight gelatin, 60% "Hi-Velocity" gelatin and 80% Ammonia gelatin

Special (Ammonia) gelatin was included as a matter of possible interest. It will be noted that this explosive is also inferior to 60% "Hi-Velocity."

There has been some comment that "Hi-Velocity," because it is a Straight gelatin type, and, therefore, has a higher nitroglycerin content, might be more sensitive to shock than the usual Ammonia grades. That such is not the case is shown by the data given in Table I. In this table, D stands for complete detonation, P for partial (local)

TABLE I

Powder	*Drop Test Results*	
	With Wrapper	*Without Wrapper*
60% "Hi-Velocity"	2P—3F	3D—2P
"Seismogel A"	2P—3F	1D—3P—1F
"Seismogel B"	1P—4F	1D—4P

detonation, and F for no detonation whatsoever. The tests were carried out by dropping an $18\frac{3}{4}$ lb. iron ball a distance of $10\frac{1}{2}$ feet onto a $2'' \times 2''$ section of powder resting upon a steel surface.

CONCLUSION

As has been mentioned previously, the explosive in most common use for seismic prospecting is 60% Ammonia gelatin. Explosives of

this classification, which includes "Seismogels A & B," have given rise to little complaint during the past several years. Prior to the investigation described in this article, however, there have been available no data on the relative performance of the various explosives for seismic prospecting when tested under working conditions. Based on the evidence presented herein, it seems very probable that full efficiency is not realized with very hard gelatins of the "Seismogel A" type in depths of water over 35 feet, or with medium hard gelatins such as "Seismogel B" in depths over 60 feet. It has been shown that Straight gelatins because of their higher nitroglycerin contents, have inherently higher velocity and water resistance than the Ammonia gelatins, and also that the Straight gelatins will retain these qualities to a much greater extent when exposed to water pressure. "Hi-Velocity" gelatin not only includes the general advantage of the Straight gelatins but, because of patented features, is much superior from the standpoint of developing full efficiency under excessive water pressures. In conclusion, it appears that the "Hi-Velocity" gelatins should be of interest to the geophysical prospector for two reasons: first, as the greatest possible assurance of satisfactory results under all shooting conditions, and, second, on the basis that worth while economies may well be available.

SIGNIFICANCE OF SOME FUNDAMENTAL PROPERTIES OF EXPLOSIVES, WITH SPECIAL REFERENCE TO GEOPHYSICAL PROSPECTING

H. E. NASH AND J. M. MARTIN*

ABSTRACT

This discussion is concerned with certain factors influencing the results from explosives in geophysical prospecting. The study is intended to acquaint the geophysicist with the pressures developed in the drill hole when the explosive charge is detonated, the temperature of the explosive gases, the amount of available energy released, and the proportion of this energy which is converted into useful seismic energy.

It is the purpose of this paper to discuss some of the fundamental developments that occur at the shot point when an explosive charge is detonated. We know that this explosive charge, when detonated, initiates elastic earth waves. But the reaction that develops the explosive energy is not generally understood. Any study of this subject must be predicated on theoretical considerations, because the many limiting factors create an inexhaustible variation of conditions, all of which would involve changes in the calculations which follow. Some of the important practical factors affecting results include variations in underground structure, and the degree of confinement of the charge. This discussion has practical value, however, in pointing out, generally, the factors that influence the results of explosives in geophysical prospecting. This study is intended to acquaint the geophysicist with the pressures developed in the drill hole when an explosive charge is detonated, the temperature of the explosive gases, the amount of available energy released and the proportion of this energy which is converted into useful seismic energy at the shot point.

The following theoretical development which has been reviewed by Berthelot (1), Stettbacher (2), Jouguet (3), and many others, is concerned with (a) the quantity of energy released per unit weight of explosive, and (b) the volumes, pressures, specific heats, and the temperature of the gases produced by the detonations. The treatment is essentially a thermodynamic one, in which only the initial state of the explosive is considered before detonation, and the final state after detonation, where the gases are confined at high pressure within a closed volume. This treatment disregards the important, but extremely complicated kinetic processes involved, or what we may call the mechanics of the reaction.

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The energy developed by an explosive on detonating is converted into a number of forms. Only a small part of the total energy is available for initiating seismic waves. Some of the energy is expended in enlarging the drill hole, crushing the surrounding material, and moving out the confining medium. Most of it, however, is eventually dissipated as heat developed near the shot point.

THE EXPLOSION TEMPERATURE

When the explosive detonates, a number of gases are generated suddenly within the closed volume, and the heat of the reaction serves to raise these gases to very high temperatures, of the order of 3000°C. The calculation of the temperature involves first, the calculation of the heat of the reaction at room temperature for a unit weight of explosive, and then, the comparison of this heat with the heat necessary to raise the products of combustion to a stated temperature. A temperature is found at which the heats are equal. This gives the explosion temperature.

The method is best shown by practical illustration. For this purpose we have selected a 60% Ammonia Gelatin Dynamite, which is a type widely used in seismograph prospecting. A typical formula given by the Bureau of Mines (4) is shown below. Inasmuch as the paraffined paper wrapper is consumed during the explosion, this is generally included as part of the explosive. The wrapper is calculated for a $2 \times 16''$ paraffin paper shell.

60% Ammonia Gelatin

Nitroglycerin	35.3 Gms.
Nitrocotton	.7
Ammonium Nitrate	20.1
Sodium Nitrate	33.5
Carbonaceous	7.9
Antacid (Calcium Carbonate)	0.8
Moisture	1.7
	100.
Wrapper	6.3
	106.3

In detonation, the above ingredients enter into a series of chemical reactions, which may be expressed by the single equation:

$1.46\,C_3H_5(NO_3)_3+0.0067\,C_{24}H_{31}O_{38}N_9+2.36NH_4NO_3+3.72\,NaNO_3+0.204C_{15}H_{22}O_{10}+0.89H_2O+0.163C_{19}H_{38}O_6+.08\,CaCO_3\rightarrow 8.72CO_2+2.13CO+14.23H_2O+0.45H_2+6.41N_2+1.86Na_2O+.08CaO.$

The ingredients are here expressed in moles contained in one kilogram. We have indicated the molecular weight of the ingredients, but this is not necessary, the real requirement being that the correct number of gram-atoms of carbon, hydrogen, etc., be given, and the correct weight of each ingredient.

The reaction might be written, without further knowledge, in many ways other than the one selected here. It is not apparent, for example, just how the oxygen might be distributed in the products of combustion. The correct equation that expresses the reaction immediately after detonation is given by a number of equilibrium constants. Two important equilibrium constants are the "water-gas" and the $CO-CO_2$ equilibrium constants, given below:

$$K_1=[CO][H_2O]/[CO_2][H_2]$$
$$K_2=[CO]^2[O_2]/[CO_2]^2$$

In these expressions, the quantities in brackets are to be expressed in moles per liter. It will be noted that for the frequently more important equilibrium, K_1, the effect of the volume occupied by the gases cancels out.

The numerical values of K_1 and K_2 depend on the temperature of the reacting gases. The values of K_1 and K_2, given in Table I, are based upon a recent compilation of dissociation equilibria by Lewis and Von Elbe (5). Temperatures are given in °K.

TABLE I

Temperature (°K)	K_1	K_2
2000	4.55	
2200	5.21	
2400	5.78	
2600	6.22	
2800	6.59	
3000	6.92	
3200	7.21	.00251
3400	7.45	.0100
3600	7.64	.0391
3800	7.82	.141
4000	8.00	.501
4200	8.16	1.58
4400	8.31	5.01

There are other equilibrium constants which must sometimes be considered, but the two listed here are all that are needed for our purposes.

In the example being treated, 60% Ammonia gelatin, the temperature of the reacting gases was assumed to be 3400°K (3127°C). It will be found that the reaction as written will give the correct numerical value of K_1 of 7.45, for 3400°K. Since we are concerned with an enclosing volume of about one liter per kilogram of explosive, K_2 shows that the concentration of oxygen molecules is negligible. It remains to be proven, however, that the assumed temperature of 3400°K is actually the temperature of the reacting gases.

Having determined the reaction, at least tentatively, it is now possible to compute the heat evolved when the reaction proceeds from left to right at room temperature. For this purpose we require the Heats of Formation of the ingredients and products. These are included in Table II. Each ingredient and product must be multiplied by the number of moles represented, per kilogram of explosive. The computation is indicated in Table II.

TABLE II

Compound	*Moles, M*	*Heat of Formation, H (Kg. Cal./mole)*	*Product H×M (Kg. Cal.)*
Ingredients			
Nitroglycerin	1.46	96.5	141
Nitrocotton	.0067	678.	5
Ammonium Nitrate	2.37	88.1	210
Sodium Nitrate	3.72	110.7	411
Carbonaceous	.204	463.	95
Calcium Carbonate	.08	270.	22
Moisture (liquid)	.89	68.	61
Wrapper	.163	449.	73
		Total for Ingredients	1018
Products			
CO_2	8.72	97.0	844
CO	2.13	29.0	62
H_2O	14.23	58.0	826
Na_2O	1.86	100.7	186
CaO	.08	152.	12
Constant volume correction	31.94×.545		17
		Total for Products	1947

Heat evolved = 1947 − 1018 = 929 Kg. Cal.

The gases, H_2 and N_2, do not appear, since their Heats of Formation are zero. The constant volume correction is made to take into account the fact that the reaction being considered proceeds at constant volume. The correction amounts to 0.545 Kg. Cal. per mole of gas evolved.

The heat evolved is now compared to the heat necessary to raise the products of the reaction up to the explosion temperature. The heat capacity data essential for this computation have been arranged

in Table III and are based upon data collected by Lewis and Von Elbe (5). Listed under each compound is the heat required to raise one gram mole of the compound, at constant volume, from room temperature to the stated temperature. Sodium oxide is considered a gas over the temperature range shown. Calcium oxide is calculated as a solid up to 2843°K, as a liquid to 3123°, and as a gas thereafter.

TABLE III

°K	CO_2	CO	H_2O	H_2	O_2	N_2	Na_2O	CaO
2000	18.68	10.23	13.91	9.31	10.91	10.09	40.95	21.70
2200	21.18	11.56	15.97	10.55	12.37	11.42	43.01	25.20
2400	23.74	12.91	18.04	11.84	13.87	12.76	45.08	28.90
2600	26.33	14.29	20.19	13.16	15.38	14.11	47.23	32.80
2800	28.95	15.67	22.41	14.50	16.90	15.48	49.40	36.90 (s)
3000	31.50	17.04	24.59	15.84	18.44	16.85	51.60	68.70 (l)
3200	34.10	18.48	26.70	17.19	19.97	18.23	53.74	128.87 (g)
3400	36.80	19.88	28.90	18.51	21.50	19.65	55.94	130.28
3600	39.50	21.29	31.10	19.98	23.10	21.05	58.14	131.69
3800	42.20	22.72	33.30	21.40	24.63	22.50	60.34	133.12
4000	45.00	24.15	35.50	22.80	26.16	23.95	62.54	134.55
4200	47.90	25.58	37.74	24.25	27.69	25.40	64.78	135.98
4400	50.80	27.01	39.98	25.70	29.22	26.85	67.02	137.41

To obtain the heat necessary to raise the products of combustion to a given temperature, the number of moles of each component of the gas is multiplied by the heat content at that temperature. The following calculation for 60% Ammonia gelatin is typical.

TABLE IV

Moles		*To 3000°K*		*To 3200°K*	
		Heat Content per Mole	*Heat Required (Kg. Cal.)*	*Heat Content per Mole*	*Heat Required (Kg. Cal.)*
CO_2	8.72	31.50	273	34.10	297
CO	2.13	17.04	36	18.45	39
H_2O	14.23	24.59	350	26.70	380
H_2	.45	15.84	7	17.19	8
N_2	6.41	16.85	108	18.23	118
Na_2O	1.85	51.60	96	53.74	99
CaO	.08	127.39	10	128.9	10
Total			882		951

Since 929 calories are available, by interpolation

$$\text{Explosion Temperature} = 3000 + \frac{929 - 882}{951 - 882} 200 = 3136°\text{K or } 2863°\text{C}$$

The interpolated temperature lies so close to the temperature assumed for the equilibrium constants, that further adjustment is un-

necessary. If the assumed temperature had departed greatly from the temperature finally determined, it would have been necessary to repeat at least part of the calculations, using a new assumed temperature.

FURTHER DERIVATIONS

If we assume the perfect gas law to hold true at the temperatures and pressures existing, $PV=NRT$, where P is the pressure, V the volume, N the number of moles contained in the volume V, T the absolute temperature of the gases, and R the gas constant. If P is expressed in atmospheres, and V in liters, R will equal .082 atmosphere-liters per degree. Inasmuch as PV has the units of energy, it also can be expressed in kilogram-meters, and R then has the value 0.846 kilogram-meters per degree.

Since N, R and T are known, the value PV can be calculated. For the example 60% gelatin—

$N=8.72+2.13+14.23+.45+6.41+1.86=33.79$ moles

$R=.082$ atm. liters per degree

$T=3136°\text{K}$

$PV=8700$ atm. liters.

If V is known, P can be computed. When the explosive is detonated in its own volume, the maximum pressure is derived. However, the deviation from the perfect gas law is very large at these densities and the pressure thus calculated is many times too low. An attempt to arrive at a more reliable value was made by Schmidt (6), who gives a curve for computing the true pressure, P', from the calculated value of P. His function is reproduced in Figure 1.

For the example 60% gelatin, when V is considered to be the volume of the explosive before detonation—

$D=1.50$

$V=0.667$

$P=8700/0.667=13{,}100$ atm.

$P'=47{,}000$ atm. $=690{,}000$ lbs./sq.in.

As the products of the detonation expand, a certain amount of work will be done on the confining walls. If the expansion is considered to be adiabatic and reversible, as far as the reacting gases are concerned, the work done may be calculated from the formula,

$$W=\frac{PV}{n-1}\left[1-\left(\frac{V}{AV}\right)^{n-1}\right]=\frac{NRT}{n-1}\left[1-\left(\frac{1}{A}\right)^{n-1}\right]$$

where P, V, are the initial pressures and volumes, AV is the volume to which the gas expands; that is, A is the "expansion ratio," and n is the ratio of the specific heat of the reacting products at constant pressure to that at constant volume. In deriving the formula, it was assumed the perfect gas law holds over the range, that no further reactions between the gases take place as the temperature is lowered, and that the specific heats are constant.

TABLE V

	Density	*Explosion Temp. °C.*	*Explosive Strength PV (f) (atm.-liters per kg.)*	*Explosive Strength or f (kg.-meters per kg.)*	*Total Energy content (kg.-meters per kg.)*	*Maximum Pressure (Lbs. /sq.in.)*
Black Powder	1.2	2380	2,810	29,000	283,000	65,000
Trinitrotoluene (TNT)	1.59	2820	8,080	83,300	405,000	690,000
Nitroglycerin	1.60	3900	11,800	121,000	479,000	1,200,000
100% Blasting Gelatin	1.37	3820	12,200	126,000	536,000	1,000,000
60% Straight Dynamite	1.30	2520	9,030	93,000	346,000	716,000
60% Amm. Gel.	1.43	2860	8,700	90,000	396,000	690,000
60% Str. Gel.	1.50	3170	8,840	91,000	460,000	670,000
30% Amm. Gel.	1.56	2320	6,600	68,000	334,000	490,000

Since n is about the same for most dynamites at their explosion temperature and equal to 1.20, the formula shows that for a given expansion the ability of a dynamite to do work is proportional to PV or NRT, which we have already derived. NRT is, therefore, often called the "explosive strength" of the dynamite and is designated by the letter f. This should not be confused with nitroglycerin strengths and other strength scales based on practical tests.

As the expansion, and thus A, is increased, the available work increases. Practically the only useful work that is obtained from an explosive is done during the early stages of the expansion. For the work to be equal to NRT or f, the expansion, A, is about 3.05, and for 2.0 f, about 12.9. These values of energy are considerably less than the total energy content of the powder. For example, f for our example 60% gelatin is 90,000 kilogram-meters per kg. but the total energy is 929 kg. cal. or 396,000 kilogram-meters per kg. In seismograph prospecting the useful part of the expansion must be quite small.

COMPARISON OF SEVERAL EXPLOSIVES

The constants characteristic of the 60% Ammonia gelatin, on the above formula, have also been calculated for some of the better known explosives. These are given in Table V. The values for Black Powder and Trinitrotoluene are taken from Cranz (7).

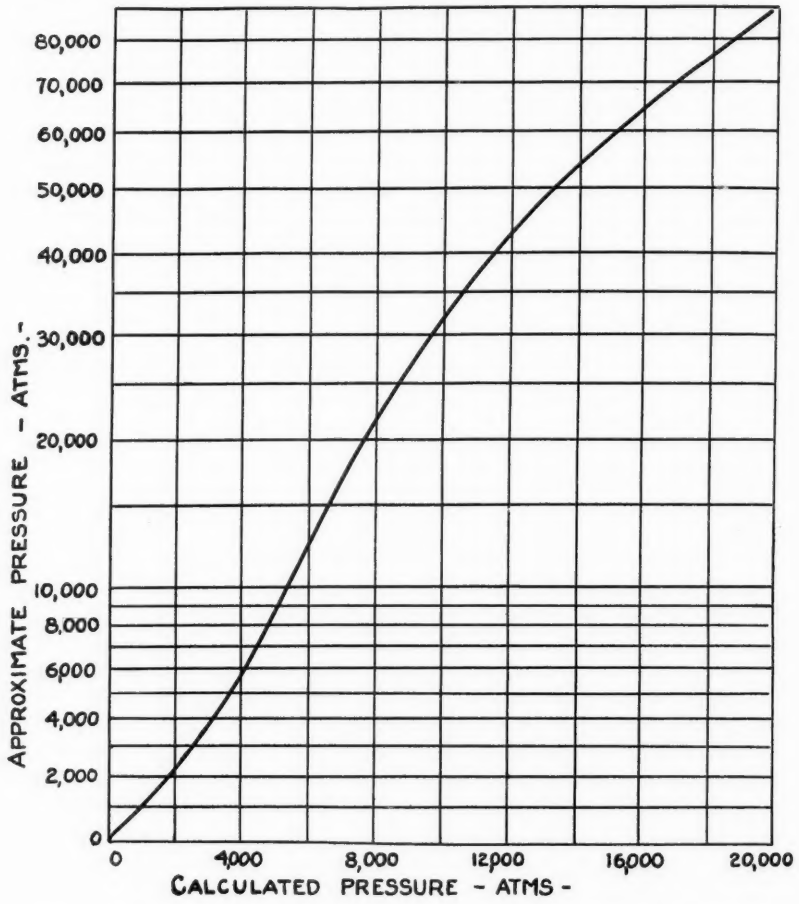

FIG. 1. Schmidt's curve giving approximate true Pressures, P', developed by an explosive, from pressure calculated according to the equation, $P=NRT/V$

The data is of interest in showing that the constants calculated in this manner fit in very well with other known facts regarding the different types of explosives. For example, all explosives of 60% grade have nearly the same "explosive strength," as it should be, if f is

related to strengths as determined by laboratory tests and field trials. High strength powders have higher "explosive strengths," and indeed, these values are in fair quantitative agreement with many tests that are used to measure the relative strengths of the different grades.

THE TIME FACTOR

The calculations given here have left out of consideration the very important factor of time. The detonation does not occur in-

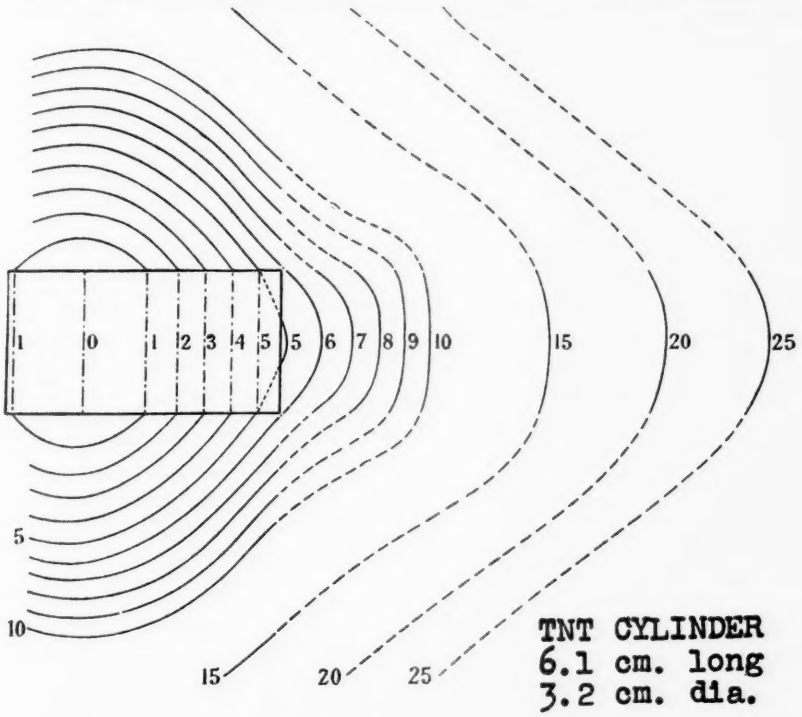

FIG. 2. The position of the detonation wave in the explosive and the shock wave in the surrounding medium at intervals of one microsecond. The explosive used was a cylinder of TNT, 6.1 cm. long, 3.2 cm. dia., detonated near one end

stantly, but proceeds at a definite rate along the column of explosive, which may vary from 1500 to 8000 meters per second, depending on the explosive and conditions under which it is detonated. An additional factor involving time is the momenta of the gases. If the explosive is shot in a drill hole, for example, in which the space around the explosive contains only air, the gases produced by the detonation

do not fill the whole space instantly but a series of complex phenomena first enters into the picture.

A shock or compression wave first proceeds from the explosive, propagated by the air medium surrounding it. Jones (8) has measured the progress of this compression wave in a series of interesting experiments. Some of his results are reproduced in Fig. 2. The rectangle represents a stick of TNT, 6.1 cm. long and 3.2 cm. diameter, detonated near one end with a blasting cap. Each line shows the position of the front of the disturbance at intervals of 10^{-6} seconds. The detonation proceeds at uniform velocity of 6200 meters per second along the cartridge. The velocity in free air remains practically unchanged as the disturbance leaves the sides and ends of the explosive. With some explosives, the velocity of the disturbance in air may exceed the rate of detonation along the cartridge. The velocity beyond the cartridge gradually decreases, finally arriving at the velocity of sound in air.

The compression wave in the medium is followed by the products of combustion. Gawthrop, Shepherd and Perott (9) have recorded the two phenomena by means of a special photographic arrangement. A typical photograph is shown in Fig. 3. The recording film was made to travel at right angles to a slit at very high speed. An image of the disturbances occurring near the explosive was projected by means of a lens onto the recording film, the purpose of the slit being to restrict the recording to a very narrow field of view. Special illuminating arrangements were used to obtain images of the shock waves. About six grams of explosives were shot, just outside the field of view. The first disturbance to appear was the shock wave, which was then followed by the products, traveling at a lower velocity. A surface of sheet steel was placed at some distance from the explosive and the reflection of the shock wave at the obstruction is plainly seen.

When these disturbances strike an obstruction, unexpectedly large pressures appear to be developed. There are numerous instances recorded where the shock wave in arriving at a solid or liquid surface raises the gas in which it is being propagated to luminosity. An interesting phenomenon in this connection was discovered by Monroe in 1888. He placed a block of nitrocotton in which were indented some printed figures, on a steel plate, as shown in Fig. 4. On detonating the nitrocotton, the printed figures were found to have been indented in the steel plate. The steel plate was drilled through under a hole extending through the nitrocotton block. It appeared that the gases

produced by the detonation exerted more force under the cavities than elsewhere. We have indicated above how the normal pressure can be calculated, but it seems evident that these pressures can be greatly exceeded if the products of combustion can gain momenta.

In geophysical prospecting the explosive is generally shot under water. Unfortunately, there is much less information available regard-

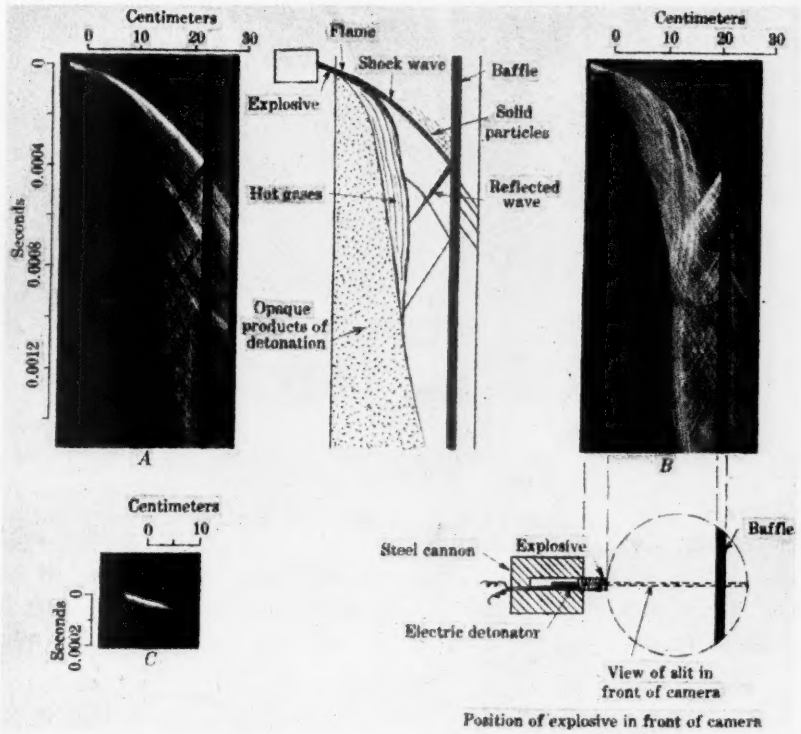

FIG. 3. Photographs showing the position of the shock wave and products of combustion proceeding from the end of a detonated charge of dynamite

ing the firing of explosives in this medium than for similar tests in air, but several investigators have made a study of the pressure waves generated in the water near a detonated charge (10). A typical record of a dynamometer, placed under water, is shown in Fig. 5. At one meter distance from the charge, two distinct waves are recorded of about equal pressure value, and separated in time by about .05 seconds. It is thought that the first is due to the compression shock,

similar to that in air, and the second is due to the expansion of the products of detonation.

Further experimental work on this phase of an explosion should result in interesting and significant developments.

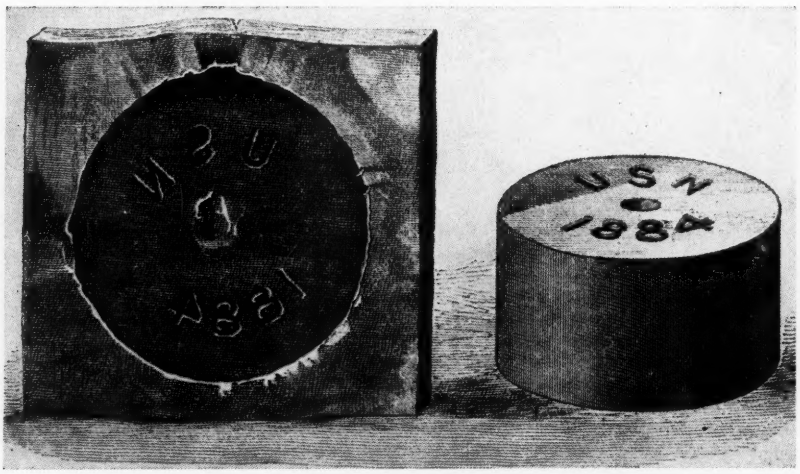

FIG. 4. The Monroe Effect. Indentations in the explosive, when detonated on a steel plate, impressed indentations in the plate

The application of the results obtained from studies such as this finds a practical use in the development of explosives best suited for particular work. Extensive field tests and much experimental work is being done by progressive explosives manufacturers to obtain com-

FIG. 5. Diagram from Dynamometer under water

parative data on the strength and performance of the various grades of explosives suitable for geophysical prospecting.

In this paper no attempt has been made to consider in full detail all the intricate and involved processes which may occur at the shot

point, but a representative sample has been given of a typical explosive reaction which it is hoped will familiarize the men in the field with the more fundamental developments resulting from the explosion of a dynamite charge in a drill hole.

The calculations of the temperature, the pressures attained by the products of the explosion, the energy evolved as heat, the available work, and the proportion of this work which is converted into useful seismic energy, should acquaint the seismologist with some of the more significant phases of the process by which elastic earth waves are initiated upon detonation of the explosive charge. The time factor, the behavior of the explosive gases in the drill hole, and their apparent action on the confining medium should furnish a basis for further study and development of this phase of the explosive process.

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(5) Lewis and Von Elbe, J. Am. Chem. Soc. *57*, 612–614, (1935).
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(10) Marshall, "Explosives," Vol. 2, P. Blakiston's Son & Co., Philadelphia, (1917).

THE AMPLITUDES OF WAVES TO BE EXPECTED IN SEISMIC PROSPECTING

B. GUTENBERG[1]

ABSTRACT

A method of calculating the amplitudes of bodily waves in earthquakes is applied to a study of the amplitudes of longitudinal waves produced by an artificial explosion. Formulae are given for calculating the energy of the reflected longitudinal wave arriving at the surface. The percentage of energy reflected at a discontinuity increases rapidly after the angle of incidence exceeds the critical refraction angle. However, no corresponding large amplitudes are recorded by the instruments. Instead, the maximum amplitudes of reflected waves are found near the shot point. This is because the ground movement is due both to the arriving wave and to the wave reflected downward from the ground. The amplitude of this movement depends, besides, on the rate of change of the angle of incidence with distance. It is pointed out that the same methods can be applied to a dipping bed, and that the amplitudes of the reflected waves are in general slightly larger in the up-dip than in the down-dip direction.

A method for calculating the amplitudes of bodily waves in earthquakes was suggested by K. Zoeppritz in 1908. The formulae to be used have been worked out by the author in the years following the death of Zoeppritz, and the first application to earthquake waves was made by L. Geiger and B. Gutenberg.[2] The method has since been used successfully in several investigations. The following is an application of this method in the study of amplitudes of longitudinal waves produced by an artificial explosion.

We suppose that the energy is produced at a point A (Fig. 1) on the surface of the earth, that the same amount of energy is radiated in all directions, and that there is no change in properties in horizontal directions. No assumptions are made concerning the vertical direction; the velocity may increase or decrease either gradually or suddenly with depth. We consider two rays which leave the point A (Fig. 1) under the angles of incidence i_1 and i_2 which differ by the small amount di. After refractions and reflections the rays arrive finally at the distances Δ_1 and Δ_2 at the surface which differ by the small amount $d\Delta$.

According to our assumptions, through each unit area of a sphere around A having the very small radius r, the same amount e of energy

[1] Balch Graduate School of the Geological Sciences, California Institute of Technology, Pasadena, California; Contribution No. 202.

[2] Karl Zoeppritz, Ludwig Geiger und Beno Gutenberg, Ueber Erdbebenwellen V. Nachrichten der K. Ges. der Wiss. Göttingen, math.-phys. Kl., 121–206 (1912).

is passing. The rays which leave A between the cones given by the angles i_1 and i_2 intersect the sphere in the zone

$$I = 2\pi rh = 2\pi r^2 di \sin i. \tag{1}$$

The total energy flowing between the two cones just mentioned is eI. At each reflection and refraction of the rays, the energy is split into the longitudinal and transverse reflected and refracted waves. If F

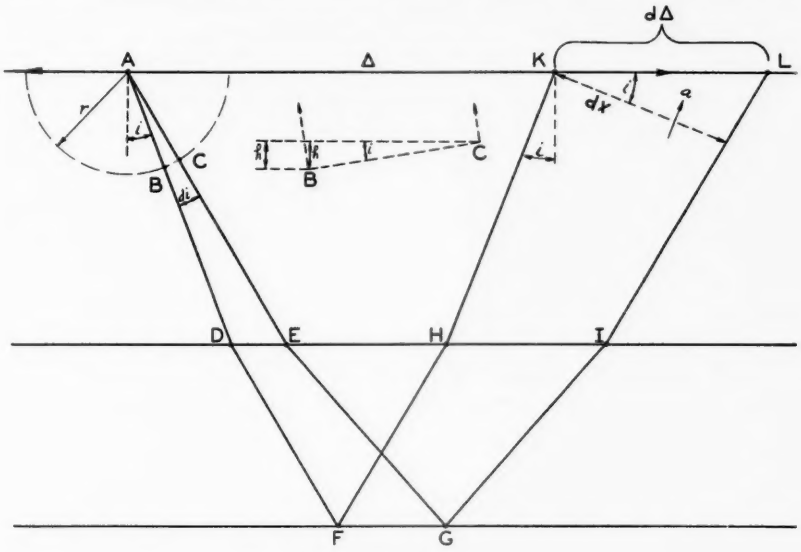

FIG. 1

is the product of all factors giving the ratio of the energy flux along the path under consideration after and before the refraction (at DE and HI in Fig. 1) or reflection (at FG), the total energy arriving finally at the surface of the earth is FeI. This energy is spread over a zone at the distance Δ from A of the width dx measured perpendicular to the energy flux and with the area $2\pi\Delta dx = 2\pi\Delta d\Delta \cos i$. The energy per unit of the area is therefore

$$E = \frac{FeI}{2\pi\Delta d\Delta \cos i} = r^2 e \frac{Fdi \sin i}{\Delta d\Delta \cos i} = C \frac{F}{\Delta} \frac{di}{d\Delta} \tan i \tag{2}$$

where C is a constant for each explosion depending on the energy generated. The amplitude a of the ground motion in the wave approaching the surface is for a given period proportional to $\sqrt{E}$. At

the surface, a longitudinal and a transverse wave are reflected, and the displacement of a particle of the surface is due not only to the amplitude of the arriving wave, but also to the movements in the two reflected waves. The direction of the ground movement, therefore, in general differs from the direction of the arriving waves, and the displacement of the ground does not only depend on the amplitude of the arriving wave but also on the angle of incidence and Poisson's ratio. If B is the factor with which E is to be multiplied in order to find the amplitude A of the ground in a given component, we find finally the fundamental equation:

$$A = cB\sqrt{F\left|\frac{di}{d\Delta}\right|\frac{\tan i}{\Delta}} \tag{3}$$

where c depends on the original energy and the period of the wave and where i is the angle of incidence at the distance Δ, where the wave is recorded.

For a given value of Poisson's ratio, B can be calculated as a function of the angle i.[3] Supposing Poisson's ratio $\sigma = 0.272$, which is a good approximation in most cases, we find the following values of B for the horizontal and vertical components of the ground movements, if the angle of incidence i is given:

i	0	5	10	20	30	40	50	60	70	80	85	90°
B_{hor}	0.00	0.19	0.39	0.75	1.08	1.36	1.57	1.66	1.61	1.26	0.83	0.00
B_{vert}	2.00	1.99	1.97	1.86	1.71	1.50	1.27	1.04	0.81	0.54	0.34	0.00

If the horizontal component is recorded, the first line must be used, in the case of a vertical component the second line.

To calculate the factor F, we must know the energy ratio between the reflected or refracted longitudinal wave and the arriving wave at each point of reflection or refraction. Formulae to calculate these ratios of energies have been given by C. G. Knott,[4] while K. Zoeppritz[5] has developed formulae to calculate the amplitudes. The calculations based on these equations show that for vertical incidence the ratio of the reflected energy E_r to the arriving energy E_a is given by

$$\left[\frac{E_r}{E_a}\right]_{i=0} = \frac{(\rho_2 V_2 - \rho_1 V_1)^2}{(\rho_2 V_2 + \rho_1 V_1)^2} \tag{4}$$

[3] For details see for example: B. Gutenberg, Handbuch der Geophysik, vol. 4, pp. 42–48.

[4] C. G. Knott, Reflexion and refraction of seismic waves, Phil. Mag. *48*, 64 (1899).

[5] K. Zoeppritz, Ueber Erdbebenwellen VII b, Nachr. K. Ges. der Wiss. Göttingen, math.-phys. Kl. (1919), p. 57.

where ρ_1 and ρ_2 are the densities in the two media, while V_1 and V_2 are the corresponding velocities of longitudinal waves. In exchanging the indices in the formula one finds that the ratio is the same whether the wave is reflected at the upper or lower side of the boundary.

In general, E_r/E_a decreases slightly with increasing i, reaches a minimum and increases then slowly. In this whole interval under normal circumstances, the larger part of the energy, frequently over 90%, is to be found in the refracted longitudinal wave. When sin i at the reflecting layer approaches the value given by the ratio of the longitudinal velocity in the first layer over the longitudinal velocity in the second layer, beyond which no refracted longitudinal wave exists, the energy of the reflected wave begins to increase more rapidly. In the early experiments with the reflection method the region where these rays reach the surface were looked for, as large amplitudes of the reflected waves were expected there, but usually no such effect was found.

This is in perfect agreement with the theory, as has been shown by calculations in which conditions have been supposed corresponding about to the velocities in the San Joaquin Valley northwest of Bakersfield. Under the assumptions made in that paper[6] the increase in the amplitudes of the reflected waves due to the larger percentage of reflected energy occurs at distances of several thousand meters from the shot point, and the amplitudes there usually are noticeably smaller than the amplitudes of the reflected waves near the shot point. The reason for this result is to be found in the other quantities of equation (3). As may be seen from the tabulation for B, its value decreases with increasing i or with increasing distance. In the case of waves reflected from the bottom of a homogeneous layer it can be easily found from a sketch that

$$\tan i=\frac{\Delta}{2d}, \text{ and therefore } \frac{di}{d\Delta}=\frac{\cos^2 i}{2d}=\frac{2d}{4d^2+\Delta^2}.$$

With these values, we find in our special case

$$A_e=cB\frac{\cos i}{2d}\sqrt{\frac{E_r}{E_a}}=\frac{cB}{\sqrt{4d^2+\Delta^2}}\sqrt{\frac{E_r}{E_a}}.$$

At the large distances where the maximum of E_r/E_a occurs, cos i is

[6] B. Gutenberg, On some problems concerning the seismic field method. Beiträge zur angewandten Geophysik, in press.

very small and prevents the occurrence of large amplitudes there together with the smaller values of B.

In the neighborhood of the shot point, B has the value 2 for records of vertical amplitudes, cos i is close to 1, E_r/E_a is given by (4) where usually we can neglect the small differences in density. We find, therefore, that in the neighborhood of the shot point the amplitudes of the reflected waves are approximately proportional to $(1/d)\ (_2V - V_1)\ /(V_2 + V_1)$, where d is the depth of the reflecting layer and V the velocities of longitudinal waves below (V_2) and above (V_1), it. A positive value of this expression ($V_2 > V_1$) corresponds to a movement of the ground in the same direction as in the original wave, downward in the case of an explosion, a negative value ($V_2 < V_1$) to a movement in the opposite direction.

If the refracting and reflecting layers have a dip, it is still possible to find the approximate amplitudes of the waves. In this case, the wave paths can be constructed in a similar way as indicated in Fig. 1, and the values of dx and i can be found graphically. In some cases investigated in this way it was found that the amplitudes of reflected waves are in general slightly larger in the direction opposite to the dip than in the direction of the dip.

NOTE ON REFLECTIONS FROM STEEPLY DIPPING BEDS

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ABSTRACT

A brief report is given of some experimental work on known geologic conditions conducted by the Pionier Company in southeastern Poland. This is a region of steep dips, severe folding, overthrusts, and step-faulting. The geologic conditions are first described, and this is followed by a discussion of the mathematical and physical aspects of the problem. It is pointed out that the problem is essentially one of three dimensions. Its solution ordinarily demands that the azimuth of shooting, in relation to strike, and the travel time relations at right angles to the strike, be known. But for the steep dips encountered in mountainous country, this is not always possible. Then the *Time Gradient* is a convenient criterion of the dip component in the direction of shooting. The problem is reduced to one of finding the time gradient in the direction of maximum dip. Curves of the time gradients are given for horizontal and for dipping beds. The method is applied to selected records and found to work well. The conclusion is reached that, where shots in different azimuths are impossible, there is an optimum azimuth, just as there is an optimum spread; but it may take much experimentation to determine where this azimuth is.

INTRODUCTION. ACKNOWLEDGMENTS

By far the greatest amount of reflection work in oil exploration is now done on gentle-dip structures. Observations have been made, in this country, on steeply dipping flanks of Gulf Coast salt domes, of paleozoic uplifts in the Midcontinent, and of structures in California and elsewhere, but they have not been described in the literature.

A brief report on studies made along this line may, therefore, be of interest. As the title of this paper indicates, an exhaustive treatment of the problem is not intended. Rather, a few examples, typical of problems of this kind, will be described. The data here utilized were obtained in the course of some experimental work on known geologic conditions, were conducted by the Pionier Company in Poland, and were made available through the courtesy of Dr. Z. Mitera.

In the following, the geologic conditions, under which the observations were made, will be described first. This will be followed by a discussion of the mathematical and physical aspects of the problem. Thirdly, a number of selected records, obtained with SSC and HRC-Askania equipments, will be exhibited and discussed relative to their geologic significance.

GEOLOGIC SITUATION

The area in which the observations were made is shown in Fig. 1. It is situated in southeastern Poland, near the Czechoslovakian

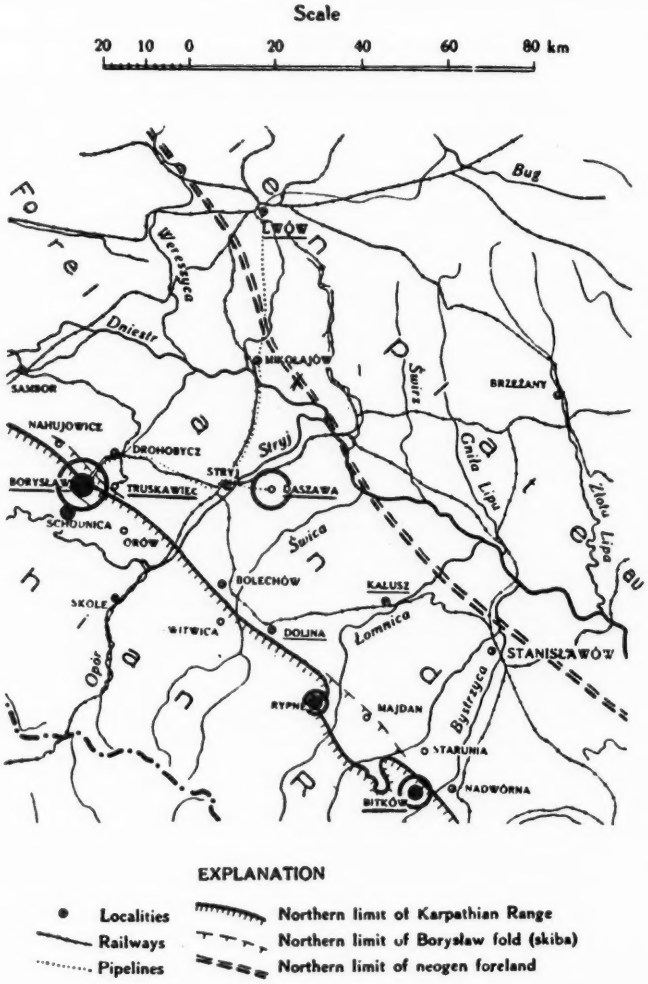

FIG. 1. Section of K. Tołwiński's map showing Polish oil and gas fields in Carpathian Mountains and Foreland

boundary, and in, or near, the Carpathian Mountains. Physiographically and structurally, the area may be divided into three zones: the Podolian Plateau in the North-East, the Carpathian Range in the

south-west, and the Foreland between them. The most important oil fields are located along the north-eastern edge of the Carpathian Range. They are: Borysław-Tustanowice, Rypne, and Bitków. In the Foreland, there is the Daszawa gas field. Some of the more important locations referred to later on in the text are underlined in the location sketch; they are: Borysław-Tustanowice, Daszawa, Bitków, Dolina and Kałusz.

Genetically, the relationship of the three zones referred to above is as follows: The Podolian Plateau is the rigid, unfolded framework which determined the strike of the folds in the Foreland and in the Carpathian Mountains. The Foreland is a depression zone on which are overthrust the marginal folds of the Carpathian Range.[1]

This situation may be illustrated in more detail by two geologic sections: one through Tustanowice-Mrażnica, and the other through Kałusz-Dolina. The former is the upper section (SE-NW) of Fig. 2 (after Tołwiński), the latter the lower section (ENE-WSW), (after Teisseyre). The situation will be more clearly understood by beginning with the lower section.

In its northeastern portion, the Podolian Plateau is noted, with Cretaceous sediments near the surface. It plunges under the Carpathian Foreland depression, and is probably stepfaulted there in a number of places. Its presence under the mantle of the foreland sediments may be proved by reflections (see Fig. 8).

Next follows, to the South-West, a part of the Carpathian Foreland consisting, at the surface, largely of Upper Miocene (Helvetian-Tortonian) sediments. They are composed of plastic clays with salt deposits and are highly folded, but considered autochtone in character, the primordial Carpathian folds of Oligocene and Eocene beds being concealed beneath them. The folds are intensified toward the South-East until they assume diapiric character, similar to the Pericarpathian salifer folds of Câmpina, Buştenari etc. in Roumania. The southwestern part of the Carpathian Foreland is an overthrust zone (Słoboda), presumably released from its substratum and therefore frequently considered as part of the Carpathian Range. In the

[1] Geologic data largely after:

H. De Cizancourt: Geology of oil fields of Polish Carpathian Mountains. *Am. Assoc. Petrol. Geol. Bull.* 15 (1), 1–41, Jan. 1931.

K. Tołwiński: Natural Gas in Poland. *Ibidem* 18 (7), 892–907, July, 1934.

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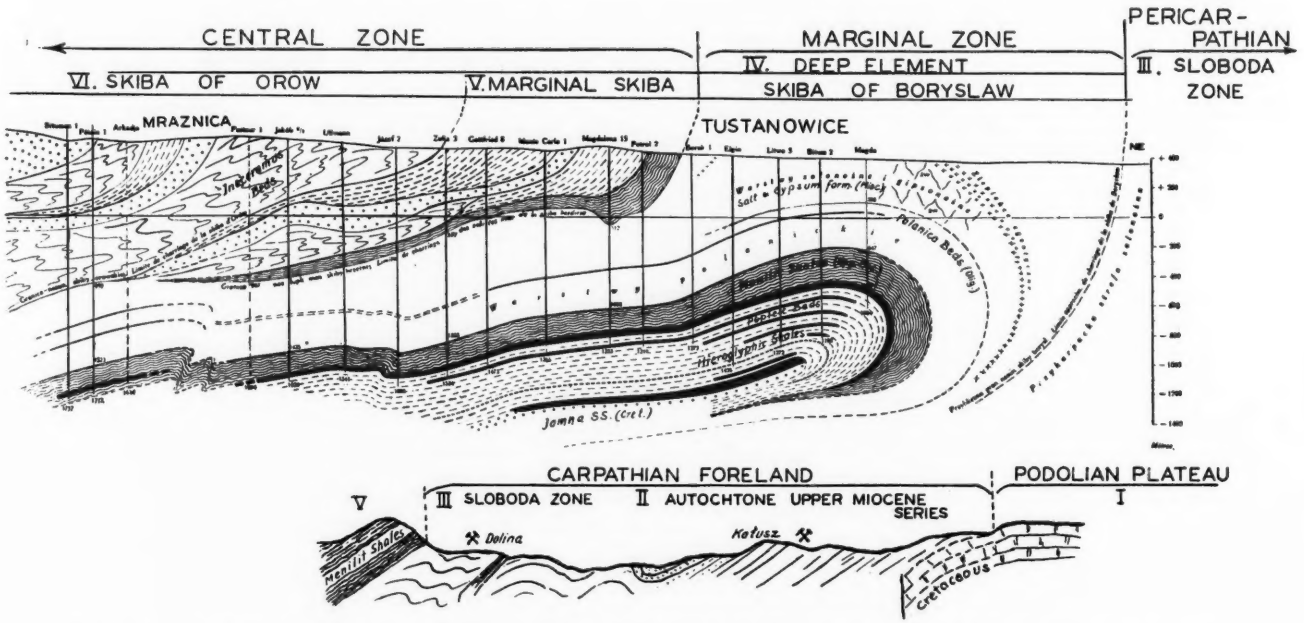
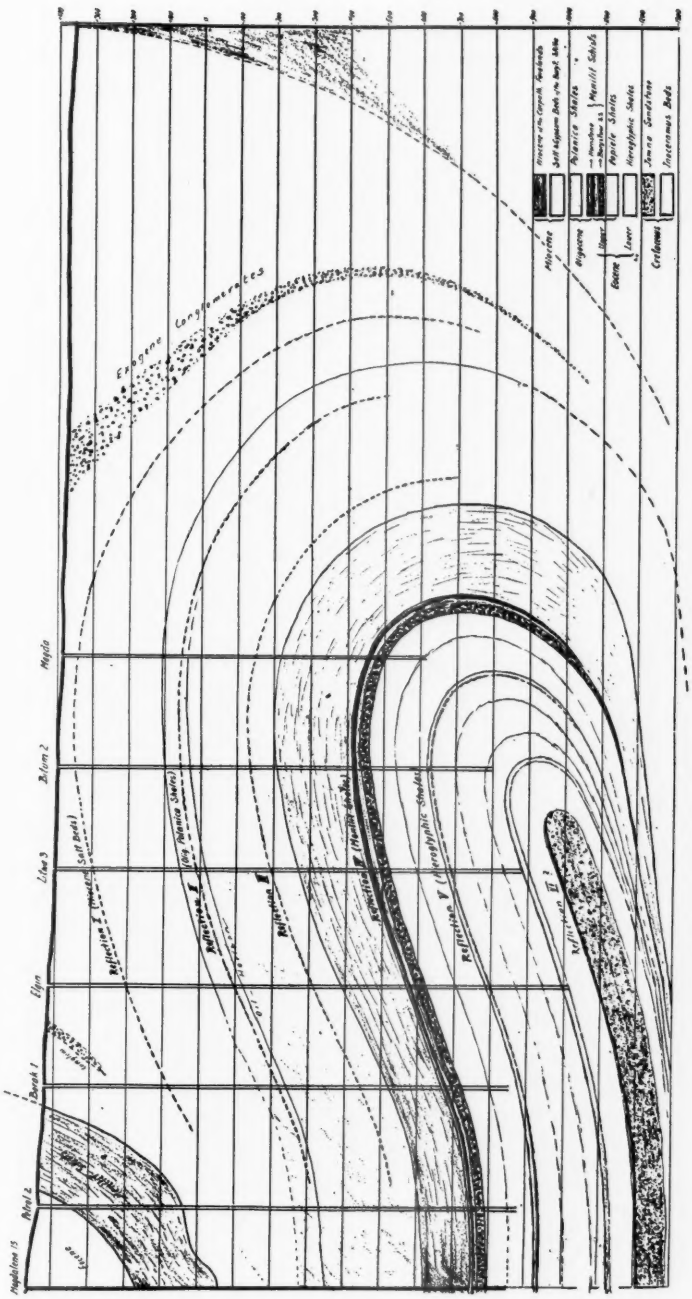


FIG. 2. (a) Geologic section through Carpathian Folds at Borysław, after K. Tołwiński. (b) Geologic section through Carpathian Foreland near Dolina and Kałusz, schematized after Teisseyre


Eocene Conglomerates
Reflection I
Reflection II
Reflection III
Reflection IV (Horizon Anhydrite)
Reflection V (Hieroglyphic Shales)
Reflection VI
Reflection VII
Reflection VIII
Reflection IX
Reflection X
Reflection XI
Reflection XII
Reflection XIII
Reflection XIV
Reflection XV
Reflection XVI
Reflection XVII
Reflection XVIII
Reflection XIX
Reflection XX
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foreland, reflection observations were made in the central, as well as in the extreme southwestern portions. Examples, shown in Fig. 9, are records obtained at Daszawa and Truskawiec.

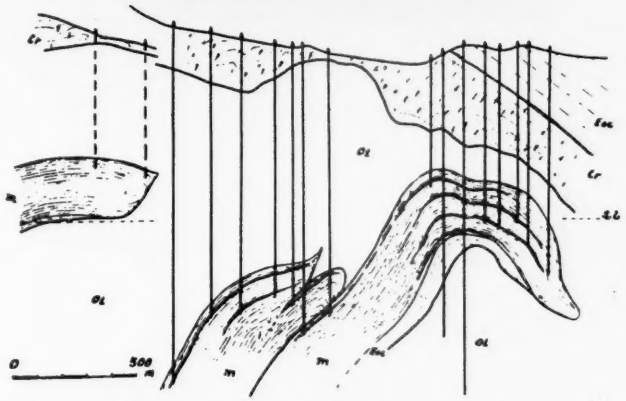
The stratigraphy and structure of the Carpathian Range is best seen from the upper section of Fig. 2. It is characterized by sediments ranging in age from Lower Cretaceous to Lower Miocene, developed in the Flysch facies i.e. alternating shales and sandstones indicating near shore diastrophic deposition during continuous orogenic movements. The old Flysch geosyncline was not folded into regular anticlines, but, due to orogenic forces of great intensity and predominantly horizontal direction, the folds were released from the substratum and subsequently overthrust upon one another (Polish: "Skiba"; French: "Nappe"; German: "Deckfalte"). Thus, the Borysław Skiba (deep element) is overthrust on the Pericarpathian or Słoboda zone, and the Central Zone (Marginal and Orów Skibas) is overthrust on the marginal zone. Attention is called to a series of folds and flexures in the upper section of Fig. 2 which makes it difficult to record consistent reflections in such types of structures as discussed below.

A number of reflections have been observed in the deep element as seen in Fig. 3. One originates in the Miocene salt bearing formations, two in the Oligocene Polanica beds, one (predominant) in the Menilit shales of the Upper Eocene, one in the Hieroglyphic shales of the Lower Eocene, and one probably in the Cretaceous in the core of the fold. In addition, reflections are believed to have been received from the Menilit shales in the bottom part of the fold. Difficulties elaborated on below were often experienced due to the contorted nature of the beds. Farther southeast, such conditions are still more evident. In the Bitków field, Polanica beds (Fig. 4) and Menilit shales are interfolded and the whole is covered with overthrust Cretaceous and Eocene strata (4b). Here, conditions were so complex and the Menilit shales so contorted (4c) that reflection results were not very encouraging.

MATHEMATICAL-PHYSICAL ASPECT OF PROBLEM

In considering the mathematical relations governing reflections from steeply dipping beds it is worth noting, at the outset, that we are dealing with a three-dimensional problem. Consequently, the azimuth of shooting, in relation to strike, plays an important part and makes the field setup, particularly in mountainous country, far

Dipping Eocene Beds-Bitków



Contorted Menilit Shales, between Bitków & Nadwórna

FIG. 4. (a) Dipping overthrust Eocene beds at Bitków. (b) Section of Bitków field, after De Cizancourt. (c) Outcrop of contorted Menilit shales, between Bitków and Nadwórna

different from what may be theoretically desirable. Mathematically, the effect of azimuth may be readily obtained when the travel time relations at right angles to the strike are known.

For gentle dip structures, the general practice is to determine dip by shooting in two profiles that differ in direction by the angle of 180°, 90°, or any other amount. With steeply dipping beds frequently encountered in mountainous country, observations in more than one

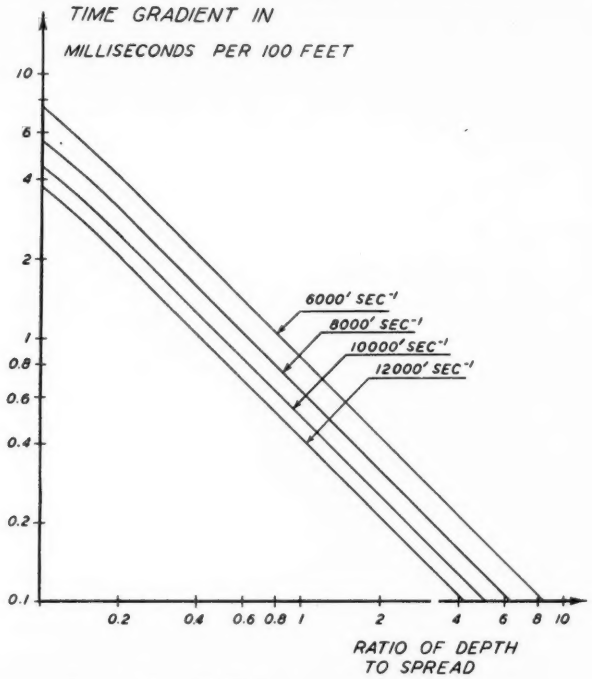


FIG. 5. Time Gradient curves for horizontal beds

azimuth, or in lines long enough to permit of up- and downdip recording, are frequently difficult. Then the *Time Gradient* will be a convenient criterion of the dip component in the direction of shooting.

The problem of determining the time gradient for the dip component in the direction of shooting may be reduced to one of finding the time gradient for the direction of maximum dip. The following diagrams represent the calculations made for that case. They are based on the assumption that ray curvature, as well as effects due to refraction offsets on overlying reflecting layers, are negligible.

As a matter of general interest, curves for the time gradient are

shown for the horizontal layer case first (Fig. 5). The ordinates represent the time gradients, the abscissae ratios of depth to spread. For both, logarithmic scales were used to obtain nearly straight line curves, as well as to facilitate interpolation for velocities different from those for which the curves have been calculated. The next diagram (Fig. 6) shows time gradient curves for up- and downdip shooting and for the range between plus and minus 30 degrees, a range

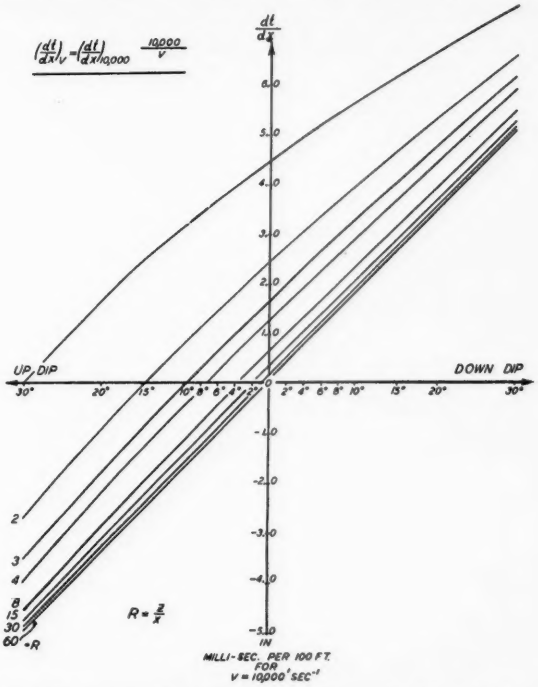


FIG. 6. Time Gradient curves for dipping beds, between plus and minus 30 degrees

that is frequently used in practice. The curves are computed for several ratios of depth to spread, but here the depth ("z") is the depth normal to the dipping layer under the shot point. Again a scale is used which makes the curves nearly straight for the ratios commonly encountered. The average velocity for which they hold is 10,000 feet per second, conversion to other velocities being readily made with formulae given in the upper left of the diagram. In Fig. 7 the time gradient, again for an average velocity of 10,000 feet per second, has been extended to include, under the same circumstances, the range up to plus and minus 90°. Finally, a diagram may be used

to show the relation between time gradient and azimuth difference of shot direction and strike, if desired.

DISCUSSION OF SELECTED RECORDS

A number of records have been selected, in order of increasing complexity of geologic conditions, to show the type of reflections obtainable from strata of varying degrees of dip. Proceeding from NW to SE in the area whose geology has been previously described, the simplest

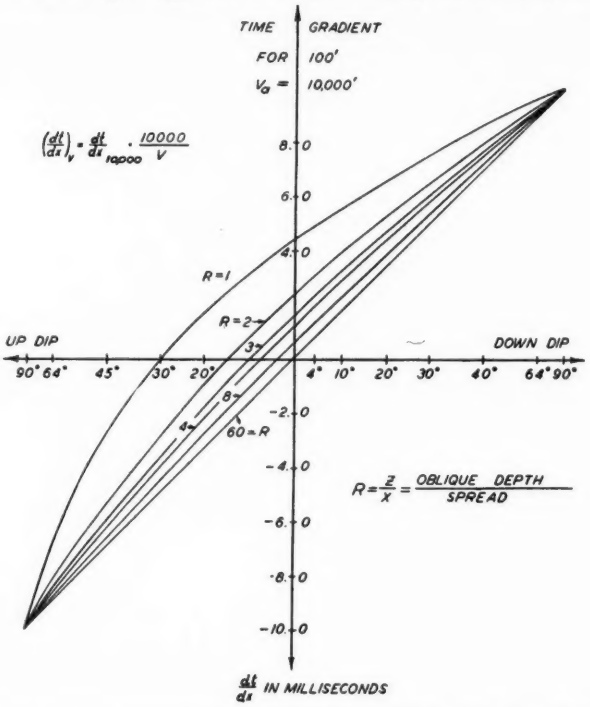


FIG. 7. Time Gradient curves for dipping beds, between plus and minus 90 degrees

conditions are encountered in the northeastern part of the Foreland where reflections may be obtained from the submerged Podolian Plateau. Fig. 8 shows a record obtained at Derżów; here, the ratio of oblique depth to mean spread is 3.4. For an oblique depth of 4106 feet, a down dip component of 4° and an average velocity of 10,000 feet per second, the diagram gives 7.2 milliseconds in 100 meters, while the record shows 7 milliseconds for the same distance. Proceeding to the center of the basin, the next record (Fig. 9a) was obtained, in the Daszawa gas field, from Miocene beds whose dip component in the direction of shooting is 18°. This record is of interest as the

oblique depth was smaller than the mean spread. The lower part of the same figure (9b) shows an opposite condition, an updip shot, where the dip component was $-30°$ for an average velocity of 8000 feet per second. The location is Truskawiec, in the Pericarpathian overthrust zone, and reflections originate in Miocene beds of moderate depth; here, the ratio of oblique depth to spread is 1.5.

Going farther southeast, into the area of the Borysław Skiba, conditions proved difficult because of the fact that the reflections were wont to disappear on subsequent stations and even spreads. Correlation by interval was virtually impossible. We sought to

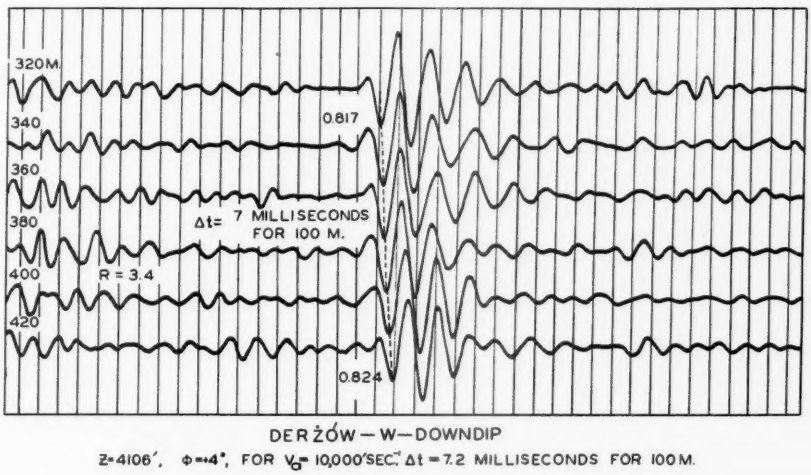


FIG. 8. Reflection from Podolian Plateau at Derzów

remedy the situation by continuous downdip and updip shooting. In the arrangement shown in Fig. 10, the last receiving point in the plus direction is the next shot point for the minus directions, and the extreme travel times are identical. Despite the fact that this made the impingement points continuous, and although some improvement was noticed by being able to trace reflections from point to point more readily, some of them would still be missing. At first, this was attributed to the possibility that near the frontal portion of the overthrust fold, the strata might be cracked, and their reflecting power be thus impaired. Careful analysis of seismograms showed, however, another explanation to be more in harmony with geologic observations (see Fig. 4c), namely, that of "superimposed" dips. From a calculation whose results are shown in Fig. 10, it is seen that only a slight superimposed "wrinkle" may not only disturb the regular

interval relationship of two reflections, but may also result in a complete disappearance of reflections at certain receptor stations. For different geometric relations of superimposed "wrinkles" and struc-

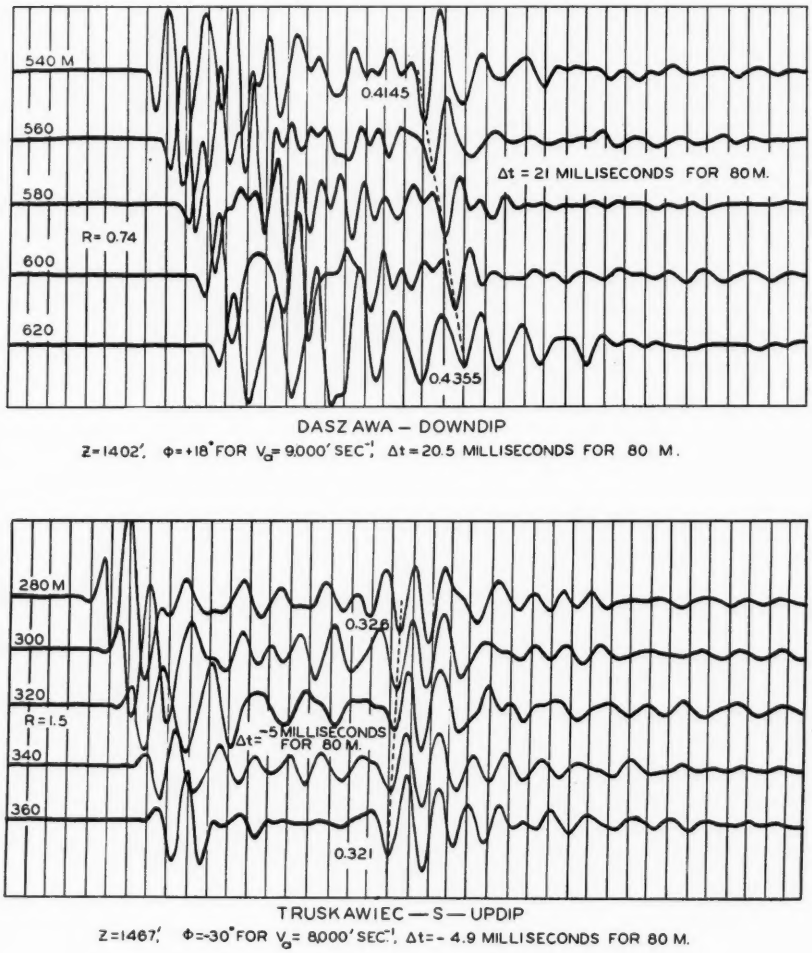


FIG. 9. (a) Reflections from Miocene beds at Daszawa. (b) Reflections from Miocene beds at Truskawiec

tural dips, it may be shown that the former would produce reflections with time gradients totally different from those of the adjacent "structural" reflections.

A record which bears this out is shown in Fig. 11. This was obtained by a down-dip shot on the southeastern flank of the Borysław-Tustanowice fold. The structural dip there is 15–20°, but this is represented only by reflection VI (probably from Cretaceous beds, in the core of the fold). The gradient of the next deeper reflection (VII) is different; depth and dip calculated therefrom would agree well

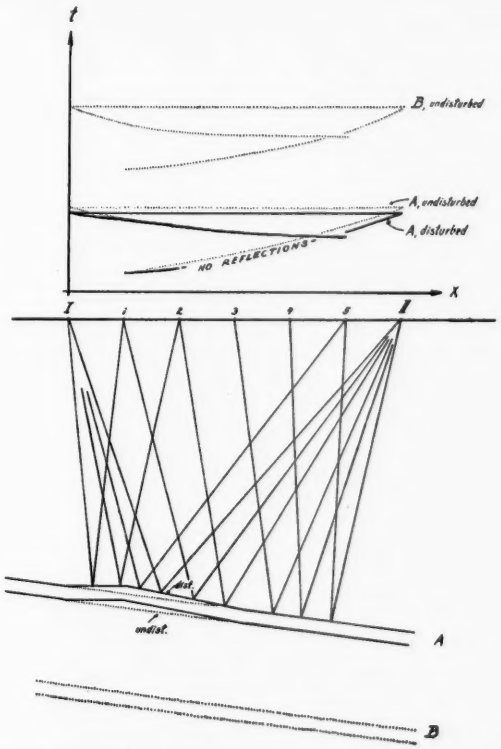


FIG. 10. Theoretical travel time curves for dipping beds with "superimposed" dip

with a reflection from Menilit shales (which ordinarily produce reflection IV) from the bottom (underturned) part of the fold. The first reflection in this part of the record, designated by IV, has a gradient totally different from that of the others. By comparison with the gradient of the first high speed refraction impulses, it follows that this is not a refraction. On the contrary, this reflection comes from one of the most prominent reflecting beds, the Menilit shales, which at the impingement point are flexured into an abnormal dip which

was computed from the record to be 56°. This is the largest dip which was definitely recorded in the area. The reflection record reproduced in Fig. 11 contains, therefore, not only reflections from a bed in its normal structural position, but also two reflections from another bed, the first being from its flexured portion on top of the fold, the second from the underturned portion of the bottom of the fold.

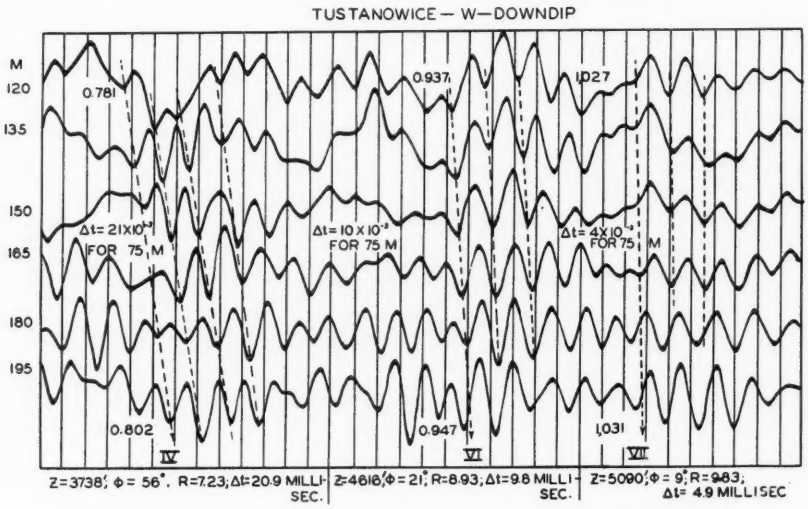


FIG. 11. Record at Borysław-Tustanowice, showing three reflections with different time gradients

CONCLUSIONS

From the type of selected records here presented, it must not be inferred that such records are the rule. Quite contrarily, the percentage of usable records obtained under such complex situations as those here described, is very small. It must be remembered that we are dealing with a three-dimensional problem and that the azimuth in which the profiles are shot also plays a very important part. There is probably an optimum of azimuth, much the same as there is an optimum of spread. Hence, it may either take much experimentation to determine where this azimuth is, or else if the topography does not permit any choice, it may be impossible to get all reflections equally well on any one location. However, the problem of determining dip and depths of steeply dipping strata is definitely solvable provided one is prepared to make the necessary sacrifice in speed of operations.

ELECTRIC EARTH TRANSIENTS IN GEOPHYSICAL PROSPECTING[1]

LOUIS STATHAM[2]

ABSTRACT

A suddenly applied electric current is passed through the earth by means of spaced electrodes. The form of the potential transient as it appears outside the current electrodes is studied. The potential transient is extremely rapid and refined methods of recording are necessary. Means for measuring the relative times of the transient potentials received from different points are discussed. A survey taken over a known deep salt dome is shown; anomalous times of the transients are found to exist over the dome. No correlation is seen between the times of the transients and the resistivity as found by ordinary electrical methods.

The distribution of steady state potentials about charged electrodes as applied to geophysical prospecting has been the subject of much investigation. Less attention has been given to the use of electric transients.[3] It is the purpose of this investigation to find if a study of the transient electric fields may reveal any information concerning the geologic structure of the earth which has hitherto not been seen in the study of the steady state potentials.

When a source of direct current is suddenly applied between two electrodes in the earth, a transient electric field is produced. In the steady state, the electric field becomes the gradient of the electric potential. In the transient state, however, the potential field is not defined, but we may measure the total electric field between two points by means of electrodes, which we shall designate as the potential electrodes, although it is understood that the difference of potential thus measured is not to be confused with the potential field.

Theoretical treatment of the mutual impedance of grounded lines and of the transient electric fields associated with grounded lines may be found in previous publications,[4] and will not be discussed here. These results indicate that the transient is slowest when the potential

[1] Presented by permission of the Board of Directors of the Humble Oil and Refining Company, Houston, Texas.

[2] Research Geophysicist, Geophysics Department, Humble Oil and Refining Company.

[3] L. W. Blau Patent No. 1,911,137, granted May 23, 1933.

[4] Ronald M. Foster, "Mutual Impedance of Grounded Wires Lying on the Surface of the Earth," *Bell System Technical Journal*, 10, 408–419 (July, 1931).

John Riordan, "Transients in Grounded Wires Lying on the Earth's Surface," *Bell System Technical Journal*, 10, 420–431 (July, 1931).

electrodes are adjacent to each other, and both are outside of, and in alignment with, the current electrodes. The time of duration is shown to increase with the conductivity of the medium and with the distance from current to potential electrodes.

PROCEDURE

The transient employed was that of the sudden application of a flow of direct current. The transient current was caused to flow between two electrodes spaced several thousand feet apart, and the transient electric field was observed by means of another pair of electrodes lying approximately in the same straight line but outside of the pair of current electrodes. Such a setup has been described in a previous discussion of a similar experiment.[5]

The potential electrodes were connected through a direct coupled amplifier to the vertical deflection plates of a cathode ray oscillograph tube, the horizontal deflection plates of which were connected to a linear sweep circuit.

The amplifier consisted of two type 954 tubes directly coupled with 250,000 ohm plate resistors. Short leads were used throughout in its construction in order to minimize distortion. With this amplifier, a voltage gain of about 20,000:1 was realized. This comparatively large gain was found to be necessary on account of the inherent insensitivity of cathode ray oscilloscopes.

The oscillograph tube and sweep circuit were of a standard manufacture, and were made for use with 110 volts alternating current. In field practice, the source of alternating current was a dynamotor driven by a storage battery. The sensitivity of the oscillograph tube was about one inch of beam displacement for 75 volts applied across the deflection plates. When used in conjunction with the direct coupled amplifier, the total sensitivity was about one inch displacement for four millivolts.

The timing of the transient may be accomplished in a number of ways. E. V. Sundt and G. H. Fett[6] discuss a method for timing transient cathode ray oscillograms by means of a periodic de-focussing voltage applied to the focussing electrode of the oscillograph tube, resulting in an image which appears on the fluorescent screen as a

[5] J. C. Karcher and Eugene McDermott, "Deep Electrical Prospecting," *Geophysics*, 5, 64–77 (1934–1935).

[6] E. V. Sundt and G. H. Fett, "A Timing Method for Cathode Ray Oscillographs," *The Review of Scientific Instruments*, 5, 402–404 (November, 1934).

chain of equally spaced dashes, the spacing being controlled by a standard frequency oscillator.

A simpler timing method, and one which was found to be satisfactory in this use, can be arranged by setting the length of the sweep to a fixed gauge and regulating the frequency of the sweep with a tuning fork. If the sweep circuit is one which is capable of maintaining its frequency constant for a reasonable length of time, considerable accuracy can be obtained in this manner.

The image on the fluorescent screen can be photographed with an ordinary still camera, and duplicate photographs are possible if care is taken that the focus and position of the camera are not disturbed between recordings.

FIG. 1

In the manner outlined above, transients were recorded at widely separated points. In most instances, the records were taken with the spacing between current electrodes 2000 feet, the distance from current electrode to nearest potential electrode 500 feet, and the spacing between potential electrodes 1000 feet. One of these is shown in Fig. 1. In this record, the total length of the line represents about one fiftieth of a second. This time scale was maintained accurately constant in all the records. The amount of instrumental distortion involved can be seen from Fig. 2, whose time scale is the same as that of Fig. 1. The vertical line was drawn in pencil perpendicular to the horizontal axis. The record shows how nearly the amplifier and oscillograph can record an applied step function of input voltage, and represents the indicial admittance of the recording system. From Fig. 2, we may conclude that the instrumental distortion is so low that the record shown in Fig. 1 is an accurate record of the form of the transients which we wish to study.

Upon comparing the records taken at various locations, the differences, if any, were found to be very slight, the thickness of the line probably being as great as the spread between the fastest and the slowest transient. It was therefore decided that some other recording scheme, capable of detecting small differences between transients, was necessary, if the transients were to be made useful in geophysical prospecting.

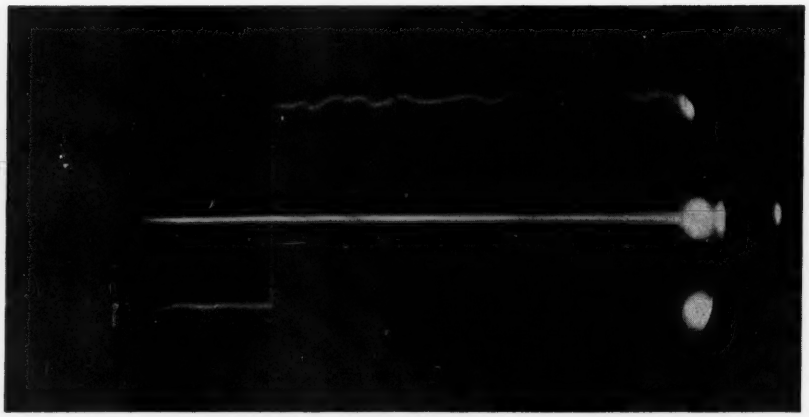


FIG. 2

A null method of measurement was then put into use. This was done by comparing the transients received from two different sources at once with the directions of polarity opposing. In this way, transients of much greater amplitude can be used, since the image representing the difference between the transients will not leave the screen, and the thickness of the line then becomes of less importance.

The circuit arrangement is shown in Fig. 3. With the currents I_1 and I_2 both flowing, the rheostats R_1 and R_2 are adjusted so that no potential is observed between P_1 and P_2. It is necessary that the currents flow in opposite directions as indicated by the arrows. Switches S_1 and S_2 are then opened, and upon being simultaneously closed again, the difference between the transient potentials may be observed on the oscillograph screen. If the two transients are equal, no potential will be observed. If, however, one of the transients rises more rapidly than the other, there will be seen on the screen a transient which, of course, contains no direct current component, since that component has been previously canceled out by the adjustment

of the rheostats. The transient component of the observed potential may now be eliminated by readjusting the distances a and b, keeping in mind that the apparent time of the transient potential increases with the distance from the current electrode. Having thus determined the proper values of a and b for equal transients, we have determined a potential time gradient without the necessity for making a photographic record or a time measurement. Anomalies can now be re-

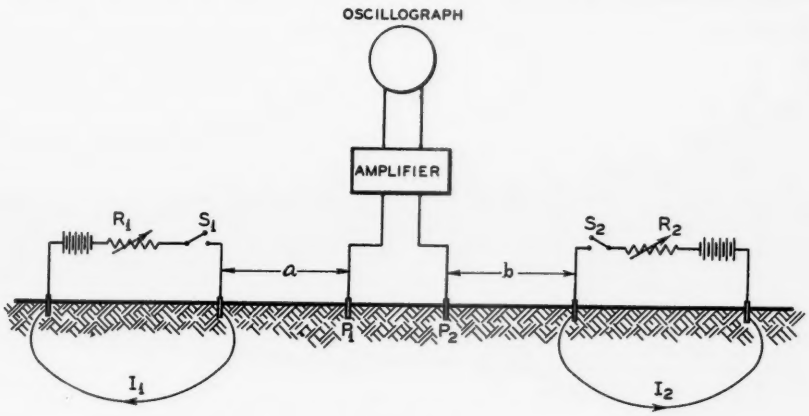


FIG. 3

corded as the direction and distance of displacement of a potential electrode necessary for the balancing of the two transients.

Among the advantages to be found in this method, it is clearly no longer so essential that the amplifier and oscillograph give a perfect reproduction of the form of the transients. In fact, filtering may be applied in order to eliminate undesirable high frequency disturbance, such as static discharges. Other forms of disturbance, as that produced by nearby telegraph and power transmission lines, can be tolerated so long as the image can still be seen clearly enough to enable the observer to determine the direction of the transient "kick."

It is essential that the two switches S_1 and S_2 be closed exactly simultaneously. This was accomplished in practice by using two thyratron relays in place of the switches. The thyratrons used were of the FG-95 screen grid type, and were connected together at their grids and filaments through large resistors. The two grids were energized simultaneously by a battery upon closing a switch, thereby causing the currents to begin to flow simultaneously in the two plate circuits, through which electrical energy was carried to the two pairs

of current electrodes. The FG-95 type of tube was chosen because of the high impedance of its grid circuit, permitting the use of large coupling resistors to prevent the transfer of electrical energy from one pair of current electrodes to the other. The reaction time of this type of thyratron tube is low, and the difference of reaction time between two tubes was found to be negligible by the device of interchanging the two firing circuits whenever a difference in transients was observed. In every case, the transient difference was found to be independent of the manner in which the thyratron tubes were connected.

The ground current was obtained from dry cell batteries, 120 volts being used on each side. The average ground current was about one ampere. The electrodes consisted of short pieces of brass pipe placed in shallow holes filled with salt water. Electrodes imbedded in sand do not give good electrical contact with the earth, and where sand was found to be present on the surface, it was necessary to deepen the holes until clay was reached.

RESULTS

Long lines were run over known geologic structures, resistivity measurements being taken along with the transient data. The setup most commonly used was as follows: Distance between current electrodes, 2000 feet; distance from current electrode to potential electrode, 500 feet; distance between potential electrodes, 1000 feet. Hence the total spread was 6000 feet, including both sides.

The results of a survey over a known producing oil field are shown in Fig. 4, in which the producing area is shaded. The length and direction of the arrows shown in the figure represent the distance and direction which it was necessary to move a potential electrode from its normal position in order to obtain a transient balance. The largest anomalies represent a potential electrode displacement of about seven hundred feet from the normal position.

Pipe lines and cased wells were found to produce negligible effects if they were not within a few hundred feet of the potential electrodes.

Where resistivity measurements are made by steady state currents, the anomalies do not seem to bear any relationship to the transient anomalies. In some areas where rapidly changing resistivities are encountered, the transient times are constant, and some very large transient differences have been found in locations where the usual resistivity measurements show the resistivity to be constant.

It is, then, apparent that electric earth transients, when used in geophysical prospecting, are influenced by changes in structure and electrical properties of the earth in some manner different from that in which steady state resistivities are influenced.

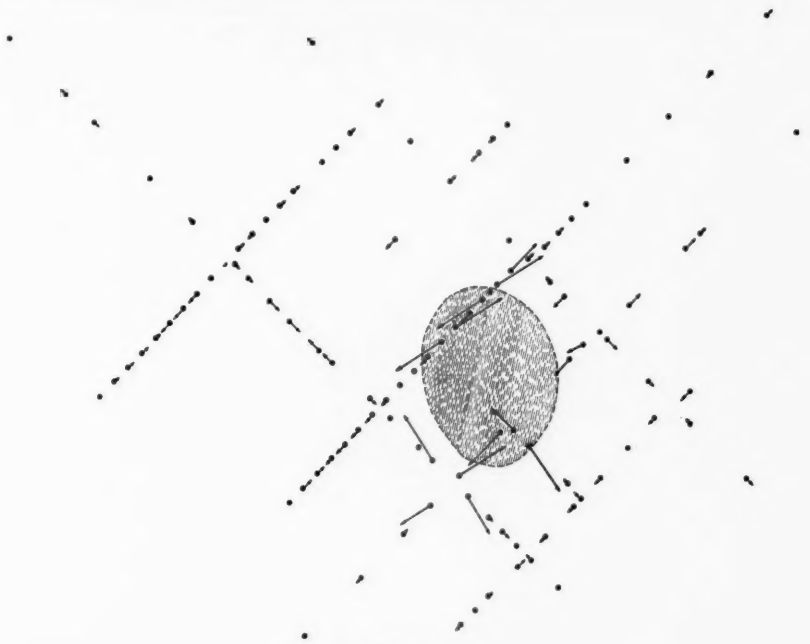


FIG. 4

Immediately after closing the switch, it is probable that almost all of the current is flowing very near the surface, and, as time goes on, the penetration of the current becomes deeper, until, at infinite time, the distribution of the current is determined by the potential function. If, then, we concern ourselves only with the form of the transient after a reasonable time has elapsed, it is possible that we may be able to distinguish between anomalous surface conditions and anomalies which are caused by deeper laid structures. Thus it is possible that a study of the transient electric fields may yield data which cannot be obtained by the usual electrical methods.

REVIEWS OF NEW PUBLICATIONS

"Geophysical Prospecting," *Reports on Progress in Physics*, vol. ii, pp. 97–128. By E. Lancaster-Jones. Published by the Physical Society, London (1936).

This chapter on Geophysical Prospecting is a brief summary of the methods most commonly used in applied geophysics at the present time. It is mostly descriptive in content, although some elementary theoretical matters are discussed, and, in a few cases, brief historical remarks are made. To the practicing geophysicist, the chapter will serve merely as light reading, but to the scientist who wants a quick perspective idea of the methods of applied geophysics, it will be of some interest.

The first method discussed is that of the torsion balance, and this is probably the most satisfying part of the chapter, considered from the point of view of completeness. Measurements of gravity by pendulum and gravity meters are mentioned next in an all too brief manner.

The paragraphs on magnetic methods discuss the various instruments and methods in common use, with a few remarks on the relative sensitivity of some of them. The case of a uniformly magnetized sphere is discussed in brief mathematical fashion.

Because of the relatively important position of the seismic methods in geophysical prospecting, the sections devoted to them will probably prove disappointing to the geophysicist. The space devoted to this is far too small; practically nothing beyond mere mention is done with the reflection method and even the information about the refraction method is of the most elementary sort. Nothing is said of "fan-shooting," and other similar variations of the seismic methods. The discussion of the instruments, too, is not as up-to-date as it well might be.

Electrical methods are then discussed, followed by electromagnetic methods and electrical well-coring. These sections are for the most part descriptive in nature, with only the most meagre references made to the theory.

A short bibliography of geophysical literature is appended.

On the whole, the chapter is best suited for the man, geologist perhaps, who wants to gather an idea as to just "what it's all about."

M. M. SLOTNICK

Flash Spotters and Sound Rangers. How they lived, worked and fought in the Great War. Compiled by John R. Innes. 308 pp. published by George Allen & Unwin, Ltd., Museum Street, London, England. $2.50.

"This book is the result of the collaboration of many persons, named and unnamed. A chapter of special interest is contributed by Prof. W. L. Bragg, O.B.E., M.C., F.R.S., who, with the aid of photos and diagrams, gives a simple explanation of the 'mysteries' of Sound Ranging. The rank and file, who are allowed to speak for themselves, make several notable contributions, and the illustrations are from sketches made by the men in their spare time at the front. Capt. Innes who was the Adjutant of the 1st Field Survey Batt. R.E., and who received a Mention in Despatches, has woven the threads skillfully to provide a pattern that is refreshingly informal, . . . the book is a serious contribution to the history of the war."—Publisher's abstract.

Primarily of historical interest, since the present applications of the seismograph in geophysical prospecting received an important stimulus from the sound ranging

methods developed during the World War. Recommended as light reading for those reflection seismograph operators who did not acquire refraction experience.

E. E. ROSAIRE

PUBLICATIONS OF THE SOCIETY OF PETROLEUM GEOPHYSICISTS

The following is a list of publications of the Society of Petroleum Geophysicists, together with dates of publication and nature of contents.

Year *Publication*

1931 *Paper No. 1, "A Universal Slope Chart for Use with Seismic Method of Geophysical Prospecting (Refractions)."* By O. C. Lester, Jr., and S. W. Wilcox was published in mimeograph form in February, 1931 as part of a group of papers presented before the Society in 1930. This paper is out of print.

1931 *Paper No. 2, "A Suggested Method of Approach for Determination of Salt Dome Overhang."* By O. C. Lester, Jr., was published in mimeograph form in 1931 as part of a group of papers presented before the Society in 1930. This paper is out of print.

1931 *Vol. I, Transactions of the Society of Petroleum Geophysicists,* was published in December, 1931 by the American Association of Petroleum Geologists and contained papers presented before the Society of Petroleum Geophysicists at the Annual Convention of the American Association of Petroleum Geologists at San Antonio, Texas, March 21, 1931; reprinted from the Bulletin of the American Association of Petroleum Geologists, Vol. 15, Numbers 11–12, November and December, 1931. This volume is out of print.

1932 *Vol. II, Transactions of the Society of Petroleum Geophysicists* was published in March, 1932 by the American Physical Society and contained papers presented before the Society of Petroleum Geophysicists at the Joint Session with the American Physical Society at New Orleans, December 29 and 30, 1931. It is reprinted from Physics, March, 1932. This volume is out of print.

1932 *"Semiportable Alternating-Current Susceptibility Meter"* by William M. Barret was published in Physics, Vol. 3, pp. 149–154, Sept., 1932 and was reprinted. Copies of the reprints are available and may be purchased from the Secretary of the Society of Petroleum Geophysicists at a price of $1.00 per copy.

1932 *Vol. III, Transactions of the Society of Petroleum Geophysicists* was published by The American Association of Petroleum Geologists in December, 1932. It contained papers presented before the Society of Petroleum Geophysicists at the Annual Convention of the American Association of Petroleum Geologists at Oklahoma City, March 25, 1932; reprinted from the Bulletin of the American Association of Petroleum Geologists, Vol. 16, No. 12. This volume may be purchased from the Secretary of the Society of Petroleum Geophysicists at a price of $5.00 to non-members and a price of $3.00 to members of the Society of Petroeum Geophysicists or The American Association of Petroleum Geologists.

1934 *Vol. IV, Transactions of the Society of Petroleum Geophysicists,* was published by the American Association of Petroleum Geologists in January 1934. It contained papers presented before the Geophysics Division of the American Association of Petroleum Geologists in Annual Convention at Houston, Texas, March 24,

1933; reprinted from the Bulletin of the American Association of Petroleum Geologists, Vol. 17, No. 1, January 1934. This volume is out of print.

1935 *Vol. V, Transactions of the Society of Petroleum Geophysicists* was published by The American Association of Petroleum Geologists at Tulsa, Oklahoma in March 1935. It contained reprints from the Bulletin of the American Association of Petroleum Geologists; from the Transactions of the American Geophysical Union; from the American Journal of Science; from the Proceedings of the World Petroleum Congress; from Physics, of the American Physical Society; and from the Proceedings of the Physical Society of London. This volume may be secured from the Secretary of the Society of Petroleum Geophysicists at a price of $3.00 to non-members, and a price of $2.00 to members of the Society of Petroleum Geophysicists or American Association of Petroleum Geologists.

1935 *Vol. VI, No. 1, Journal of the Society of Petroleum Geophysicists* was published by the Division of Geophysics, American Association of Petroleum Geologists in July, 1935. It contained many of the papers presented at the convention at Wichita, Kansas, in March, 1935. This number may be secured from the Secretary of the Society of Petroleum Geophysicists at a price of $3.00 to all.

1936. *Vol. I, No. 1, Geophysics*, a Journal of General and Applied Geophysics, was published by the Society of Petroleum Geophysicists in January, 1936. It contained many of the papers presented at the Mid-Year Meeting of the Society of Petroleum Geophysicists held at Dallas, Texas, in November, 1935. This number may be secured from the Secretary of the Society of Petroleum Geophysicists at a price of $3.00 to all.

1936 During 1936 one or more additional numbers of Vol. I, of Geophysics will be issued. These numbers will be sold to all at a price of $3.00 per copy.

The annual subscription price to Geophysics is $6.00 per volume to non-members and $4.00 per volume to members of the American Association of Petroleum Geologists. These prices may be changed in the near future.

Send orders for back numbers and subscriptions to the Secretary-Treasurer and make checks payable to the Society of Petroleum Geophysicists.

John H. Wilson
Secretary-Treasurer,
Society of Petroleum Geophysicists,
610 Midland Savings Bldg.,
Denver, Colo.

THE SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the name before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Secretary. (Names of sponsors are placed beneath the name of each nominee.)

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MINUTES OF ANNUAL BUSINESS MEETING OF SOCIETY OF PETROLEUM GEOPHYSICISTS HELD IN THE ART MODERNE ROOM, TULSA HOTEL, TULSA, OKLAHOMA, MARCH 19, 1936

At 9:20 A.M., March 19, 1936, the annual business meeting of the Society of Petroleum Geophysicists was held in the Art Moderne Room of the Hotel Tulsa, Tulsa, Oklahoma.

The meeting was called to order by the president, Dr. B. B. Weatherby. Minutes of the last meeting were read by the secretary, and approved as read.

The president called for the report of the Secretary and Treasurer. Mr. G. H. Westby gave a very comprehensive report, most of it being illustrated by slides. Acceptance of this report was duly moved, seconded and carried.

Report of the Committee on Safety was called for. Vice-Chairman Lester reported that the committee was not yet ready to make its report as they are attempting to collect data for a statistical study on accident history, preferring to use data from various companies en masse rather than by individual companies; that while there had been quite a number of the questionnaires returned, there were not yet enough to make a representative study. He suggested that the report be passed until the mid-year meeting, or until the next March meeting.

It was moved and seconded that the report of the Committee on Safety and the suggestion of Mr. Lester be accepted. Motion seconded and carried.

Dr. E. E. Rosaire, reporting for the Committee on the matter of incorporation of this Society, said that after investigation it seemed logical to incorporate in Colorado, and that as soon as final action is taken on the proposed amendments to the Constitution, incorporation proceedings will be initiated.

Moved and seconded that the report be accepted. Motion carried.

The president then announced they were ready to take up any new business of the association.

The president reported the results of election of officers for the coming year, as follows: President, L. W. Blau; Vice-President, G. H. Westby; Secretary and Treasurer, J. H. Wilson; Editor, F. M. Kannenstine.

The Secretary then read the following proposed amendments to the Constitution recommended by the Business Executive Committee:

"I. Name" should be change to read—"This Association shall be called the 'Society of Exploration Geophysicists."

"II. Object." should be changed to read—"The object of this Association is to promote the science of geophysics especially as it applies to exploration."

"III-C. Election to Membership." should be added "Provided the Executive Committee may accept applicants for either class of membership, who, because of their geographical location or because of their lack of acquaintance with active members of this Association, are unable to secure qualified sponsors, but who otherwise are eligible for membership."

"III-E. shall be changed to read—

"III-E. Code of Ethics.

"Membership of any class shall be contingent upon conformance with the established principles of professional ethics."

"V. Officers and their Duties."

A 2. Paragraph 1—"Secretary Treasurer" shall be changed throughout to read—"President."

Fourth sentence shall be changed to read—"At least three candidates for president shall be named on this ticket whenever the incumbent vice-president shall be ineligible for re-election."

After the second paragraph, a third shall be inserted to read—

"Each member shall express one choice for Secretary-Treasurer, and one choice for Editor. The candidates securing the highest number of votes so cast and counted shall be elected Secretary-Treasurer and Editor, respectively."

A 2—end of fourth sentence, third paragraph, shall be changed to read: "at the time the ballots are presented to the Nominating Committee for counting."

"By-Laws I A 2—after "regular Society Publication," insert—"shall not be eligible to vote," etc.

By-Laws II A 2—strike out "a copy of."

By-Laws III A 2—at end, after "professional cards or otherwise," add—"but shall be entitled to receive the regular publication of the Society upon payment of a fee equivalent to that charged an associate member."

Motion was made that the proposed amendment changing the name of the society be stricken. Motion seconded. After much discussion a rising vote was taken and motion lost.

Mr. Lester moved that the recommendations of the Business Executive Committee be accepted. Motion seconded; carried.

Announcement made of luncheon to be held in Tulsa Hotel at 12:00 noon.

There being no further business, motion for adjournment was made, seconded and carried.

G. H. WESTBY, *Secretary*

TECHNICAL PROGRAM, ANNUAL MEETING, TULSA, OKLA., MARCH 19–21, 1936

THURSDAY MORNING, MARCH 19, ART MODERNE ROOM, HOTEL TULSA

9:00 A.M. Business Meeting
10:30 A.M. Technical Session

B. B. Weatherby, Chairman

1. B. Gutenberg. Some Theoretical Problems Concerning the Seismic Methods.

The periods of longitudinal waves produced by explosions increase with distance in a similar way as earthquake waves. The amplitudes of the waves depend not only on the amount of energy reflected or refracted at discontinuities, but also on the angle of incidence at the instruments and its rate of change with distance. Calculations on the relative amplitudes of direct, refracted and reflected waves are in agreement with the observations. Formulae are given to calculate the approximate dip of a discontinuity using either the distance at which the travel time of the reflected wave is a minimum or the difference in travel time between two instruments, especially at two opposite sides of the shot point. The surface waves (ground roll) recorded from explosions can hardly be pure elastic waves; their velocity is too small for either Love or Rayleigh waves.

2. M. M. Slotnick. On Seismic Computations, II.

This paper is a continuation of a previous one given, with a somewhat simliar title, in which are discussed the travel-times and other similar properties of the wave paths in a medium in which the seismic velocity is an integrable function of the depth. In this paper we consider similar properties of the waves from a point on the surface to a point in a "well" in such a medium.

3. E. E. Blondeau. Earth Temperature Measurements over Two Known Structures.

Temperature measurements taken in a series of 140 foot holes across the Lucien field, Nobel County, Oklahoma, are shown, together with the geological section. Data obtained in two 450 foot holes on opposite sides of the fault plane of the Oklahoma City field are also given. In each case the results indicate no positive correlation with the known geological structure.

4. L. A. Burrows. Relation Between Firing Current and Performance in Seismograph Caps.

The time break characteristic of both "SS" and "SSS" seismograph caps are discussed. Particular attention is given to the occurrence, length, and uniformity of the various time breaks over a relatively extensive range of firing currents. Lantern slides were used to illustrate the more pertinent points.

5. See No. 25.

Society Luncheon, Hotel Tulsa.

THURSDAY AFTERNOON, JOINT MEETING WITH THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS. 1:45 P.M. CRYSTALL BALL ROOM, HOTEL MAYO

D. C. Barton, Chairman

6. C. E. Van Orstrand. Preliminary Report on Geothermal Methods of Estimating the Age of the Earth.

The normal gradient of a cooling globe may be something like 200 feet per degree Fahrenheit as actually observed in old, undisturbed rocks in northern Ontario, Canada. The substitution of this value in the equation of heat conduction instead of the usual 50 feet per degree Fahrenheit leads to an age of the earth of about 1,500 millions of years, which is about the same as that obtained by the method of radioactivity. This result implies that the heat which in escaping from the earth is not necessarily of radioactive origin.

7. D. C. Barton and Ethel Ward McLemore. Crosbyton Magnetic and Gravitational Anomaly, in Crosby, Garza, Dickens, and Kent Counties, Texas.

A large, slightly subcircular anomaly has been mapped by pendulum, torsion balance, magnetometer and dip needly near Crosbyton in northwest central Texas. The width of the anomaly is approximately forty miles. Its gravitational amplitude is 4.5 milligals; and its magnetic amplitude is 2,500 gammas. A well which was drilled to a depth of 5,105 feet near the crest of the anomaly is carried as normal by the subsurface geologists. According to mathematical calculations the anomaly must be the effect of a flattened stock-like mass whose vertical axis dips fairly steeply to the west; and whose vertical dimension is several miles; from geological considerations, it must be the effect of a basic igneous intrusion.

8. B. B. Weatherby. Presidential Address. The Organization of an Effective Exploration Department.

The author reviews the functions of a Land, Lease and Exploration Department in a large oil company, and describes in detail the integral parts. Criteria are furnished for the background of men suitable for the various positions, and a detailed organization chart is submitted which also shows the flow of information secured from the various field methods. Much stress is placed upon the need for detailed, routine reports. The part played by contracting geophysical exploration companies is also described, and the extent of the service which they should render is shown.

9. T. I. Harkins. The Geophysical History of the Darrow Salt Dome, Ascension Parish, Louisiana.

The Darrow salt dome is a piercement type dome, with cap at 4,800 feet and salt at 5,100 feet. Prior to the reflection shooting, only one well, a dry hole, had been drilled. The reflection shooting was the first case of the use of reflection dips in Gulf Coast exploration. The first well drilled at a location based on the reflection picture proved production. Later drilling confirmed it to be high on the salt.

Prior torsion-balance survey, reflection survey, and present knowledge of salt outlines are presented for comparison.

10. T. I. Harkins. The Geophysical History of the Mykawa Oil Field, Harris County, Texas.

The Mykawa oil field is apparently located over a deep-seated salt dome, as is shown by the presence of a decided gravity minimum. The field was discovered as a result of this gravity minimum.

Reflection surveys in advance of the first commercial oil production indicated a small steepsided dome in the sedimentary beds. This was the first completely dip reflection survey in the Gulf Coast. Subsequent drilling has outlined oil production at several horizons and the steepness of the structure confirmed.

The gravity and reflection maps are shown, together with comparative map of subsequent drilling.

11. J. H. Wilson. A Recommended Program for the Exploration of the Great Plains.

The known geological information, particularly with reference to possible oil producing horizons, is discussed briefly.

A method is proposed whereby the area is subjected to a reconnaissance seismic survey to determine the location of the major structural features, followed by other methods of successively higher resolving power in the favorable areas outlined by the reconnaissance.

12. F. Rieber. Controlled Directional Sensitivity. A Method for Adapting Reflection Methods to Complex Structures.

The difficulties encountered in reflection prospecting of complex structures are frequently due to the presence of several closely spaced patterns of wave trains, arriving from substantially different directions. Such waves, when superposed on a visual record of the ordinary type, result in a complex, illegible pattern. Part, and frequently all, of the information necessary for mapping the area is thereby obscured. Wave patterns predictable from theory and verified by experiments with an actual model, demonstrate clearly the necessity for directional discrimination. A complete new reflection system, embodying controlled directional sensitivity is described. Illustrations of the equipment are shown, and a description is given of the technique by which a complex wave pattern may be broken down and analyzed for individual component waves arriving from any or all possible directions.

13. J. B. Eby. Magnetic Survey of Southwest Alabama.

This paper covers briefly about a year and a half of magnetic investigations in Mobile, Baldwin, Escambia, Washington, and Clarke Counties, Alabama. The field work was conducted by E. G. Nicar, under the direction of the Alabama Geological Survey, Walter Jones, State geologist of Alabama, and the author. The paper includes a complete isogram map of the territory covered and discusses the relation of this investigation to the geology of that particular region.

14. E. E. Rosaire and K. Ransone. The Growth of Company Owned Operations in Gulf Coast Geophysical Exploration since 1930.

Available data for the operations, week by week, of the number of crews operating torsion balances, refraction seismographs, and reflection seismographs have been

plotted from July, 1930, through January, 1936. In addition, separate graphs have been plotted for company-owned and contract operations.

The results show that the refraction seismograph was practically abandoned at the end of 1930; that during 1931 there was practically no geophysical exploration by any method; that torsion-balance activity reached a peak in 1934; that reflection-seismograph activity has been steadily increasing since 1931; that the torsion-balance contractors are disappearing from the picture; and finally, that for the reflection seismograph, company-owned operations are increasing at a greater rate than contract operations.

FRIDAY MORNING. 9:00 A.M. ART MODERNE ROOM, HOTEL TULSA

E. E. Rosaire, Chairman

15. J. B. Macelwane S. J. Absolute and Relative Energy Relations in the Reflection and Refraction of Elastic Waves.

It is well known that a plane elastic wave falling on the plane boundary between different solid media in slipless contact is constrained by the boundary conditions to generate, in general, both reflected and refracted dialation or divergence waves and reflected and refracted shear or curl waves. Green's method for the determination of partition of the incident energy among the derived waves, as applied by Knott, Jeffreys, Slichter and Gabriel and others, is a relative one; but the absolute method of Love and Blut can be shown to give identical relative distributions.

16. C. E. Van Orstrand. Preliminary Report on the Geothermal Gradients in the Oriskany Sand in New York, Pennsylvania and West Virginia.

The tabulation of the reciprocal temperature gradients in 20 wells show that the gradients in the Oriskany sand have a value of about 50 feet per degree Fahrenheit, regardless of the depth of the sand. This result is interpreted to mean that the gradients are probably the result, chiefly, of elevation and subsidence. The values are only remotely related to the gradients in a normal cooling earth and are therefore of no value in estimating the age of the earth.

17. P. W. Klipsch. Some Aspects of Multiple Recording.

Considerable attention has been given to the use of more than one geophone on each recording channel with the hope of increasing the signal-to-noise ratio, where "signal" is taken to mean "recorded reflection" and "noise" means any undesired recorded amplitude. The average expectance of this gain is evaluated analytically, and the statistical distribution examined. Since at different instants this gain possesses different values dependent on a large number of causes, these causes are assumed to be random in nature; a justification of this and other assumptions is explained and the distribution of gain in terms of frequency of occurrence is expressed in the form of a probability curve. From this analysis an answer can be inferred to the question, "if n is the number of geophones, what is the probability that a gain of $k \cdot \sqrt{\pi}$ will be occur?" The average expectance of this gain is shown to be

$$\overline{G} = \frac{2}{\sqrt{\pi}} \cdot \sqrt{n} \qquad (12)$$

This leads to the conclusion that a large number of geophones per channel is necessary to obtain consistently worthwhile values of gain in signal-to-noise ratio.

Aspects incident to application are discussed, and sources of noise which are not random are mentioned.

18. A. B. Bryan. True Ground Motion from Mechanical Seismograph Records.

The method of obtaining the true ground motion from a record made with a seismograph of known period and damping, as published by H. A. Wilson and others, is reviewed and is applied to records obtained when the same ground motion is recorded simultaneously on two instruments of widely different characteristics.

19. Louis Statham. Electrical Earth Transients in Geophysical Prospecting.

A suddenly applied electrical current is passed through the earth by means of spaced electrodes. The form of the potential transient as it appears outside the current electrodes is studied. The potential transient is extremely rapid and refined methods of recording are necessary. Means for measuring the relative time constants of transient potentials received from different points are discussed. A survey taken over a known deep salt dome is shown; anomalous time constants of the transients are found to exist over the dome. No correlation is seen between the time constants of the transients and resistivity as found by ordinary electrical methods.

20. J. M. Ide. An Experimental Study of the Elastic Properties of Rocks.

Laboratory determinations of Young's modulus, rigidity, and compressibility were made on a set of representative rock samples. These measurements are compared with the theoretical relations between the elastic constants of an isotrophic medium. Computed longitudinal and transverse wave velocities are compared with direct field measurements by Leet in granite and norite. Agreement is within 5 per cent for norite, and 20 per cent for granite.

21. L. D. Leet. A Refraction and Reflection Fan to 187.8 KM.

On the fixed instruments of the Harvard Seismograph Station, at Harvard, Mass., timed quarry blasts have been recorded at distances from 35.2 km. to 187.8 km. Data for analyzing local earthquakes and for investigating the surface layers of the earth in New England are being sought.

One possible interpretation of observations at present available is discussed. It leads to a discontinuity at a depth of 23 km., with longitudinal velocities 6 km/sec. above, and 8 km/sec. below that level.

22. F. A. Tompkins. Effect of Development Time and Developer Temperature on the Production of Photographic Seismograph Records.

The effect of variation of development time and developer temperature on the production of uniform records is discussed. Graphs of these relations are shown.

FRIDAY AFTERNOON 1:30 P.M., ART MODERNE ROOM, HOTEL TULSA

E. McDermott, Chairman

23. E. A. Eckhardt. Comparative Torsion-Balance and Gravimeter Survey.

An area covering 46 square miles previously surveyed with the torsion balance was resurveyed with a gravimeter. The area was chosen because of the exceptionally good appearance of the torsion balance survey. The gravimeter survey appears to be at least equally satisfactory. From a reasonable number of check observations made in the area

the probable error of a station value has been computed to be .06 milli-gal. Pictures of the instrument and of the torsion balance gravimeter data in the test area will be shown.

24. J. A. Lewis and W. L. Horner. Interstitial Water Saturation in the Pore Space of Oil Reservoirs.

The presence of water in oil reservoir cores has been observed for several years by analysts using a direct method for fluid content determinations. The actual amount of water that is present in the sand is of importance in the estimation of oil reserves as well as in determining the type of fluid which a particular stratum will produce under conditions favorable for flow into the well. The core analysis profile of a well cored with oil (using Baker Core Barrel) is compared with three other wells which were cored with water. The analysis of the former core is in close agreement with respect to oil and water saturations, 30.58%, 44.40% respectively, with other cores in the area, and points to the conclusion that water was distributed throughout the sand section with no indication of gravitational separation at the time of coring. Coring with oil or the addition of indicators to the fluid used during coring and the subsequent analysis of same are methods for determining correct interstitial water saturation.

25. A. Graf. New Geophysical Instruments and Apparatus.

The static gravity meter as developed by Professor Haalck of Potsdam is described, and is essentially a sealed mercury "barometer" maintained at constant temperature by means of an ice bath. The apparatus for the analysis of soil gas is developed by Dr. A. Graf is also described, and is essentially a micro-calorimeter in which hydrocarbons which may be present in the soil gas are studied under quantitative conditions.

26. C. A. Heiland. Notes on Reflections from Steeply Dipping Beds.

A brief report is given of some experimental work on known geologic conditions conducted by the Pionier Company in southeastern Poland. This is a region of steep dips, severe folding, overthrusts, and step-faulting. The geologic conditions are first described, and this is followed by a discussion of the mathematical and physical aspects of the problem. It is pointed out that the problem is essentially one of three dimensions. Its solution ordinarily demands that the azimuth of shooting, in relation to strike, and the travel time relations at right angles to the strike, be known. But for the steep dips encountered in mountainous country, this is not always possible. Then the *Time Gradient* is a convenient criterion of the dip component in the direction of shooting. The problem is reduced to one of finding the time gradient in the direction of maximum dip. Curves of the time gradients are given for horizontal and for dipping beds. The method is applied to selected records and found to work well. The conclusion is reached that, where shots in different azimuths are impossible, there is an optimum azimuth, just as there is an optimum spread; but it may take much experimentation to determine where this azimuth is.

27. J. A. Sharpe. Simple Formulae of Three-Dimensional Dip Shooting.

28. L. Y. Faust. Optimum Geophone Spreads for Reflection Surveys.

The assumptions inherent in the correlation method are examined for a clue to the optimum spread. From these considerations together with a study of observed data, it is concluded that spreads of 500 feet or less are dangerous, except in areas where excellent reflection character is obtained. The advantage of a long spread in dip work is discussed.

SATURDAY MORNING 9:00 A.M., ART MODERNE ROOM, HOTEL TULSA

J. C. Karcher, Chairman

29. J. Barab, J. M. Martin, and H. E. Nash. Significance of Some Fundamental Properties of Explosives, with Special Reference to Geophysical Prospecting.

The method of calculating the explosion temperature of commercial explosives from fundamental data is described. Making several assumptions, the data can be used to derive other fundamental theoretical quantities. These calculations are made for a number of commercial explosives, and the properties thus derived are compared, with special reference to geophysical prospecting. The neglect of the time factor is the chief limitation of the method. Several illustrations are given of the manner in which an explosive, important in geophysical prospecting, are enumerated. The safety factors are discussed.

30. R. R. Thompson. The Seismic Electric Effect, and Its Use in Recording Seismic Waves.

The Seismic Electric Effect is the name which has been given to the variation of earth resistivity with elastic deformation. An account is given of experiments on the use of this effect in recording seismic waves. The recording circuit employs a direct current through the ground resistance; and the variations in resistance are recorded. Analysis of the noise appearing in the recording circuit is given and methods of reducing the noise level are described. The results of measurements on the magnitude of the effect are given, and the sensitivity obtainable with the seismic electric method is compared with that given by an electro-magnetic pickup.

31. M. M. Slotnick. A Simplified Circuit of the Seismic Electric Method and Its Steady State Solution.

The Seismic Electric Effect gives rise to the problem of finding the steady state response of a circuit consisting of an inductance and a response of a circuit consisting of an inductance and a resistance of the form $R+A \cos \omega t$ $(R>A)$ in series with a D.C. input. In this paper a solution is given, other than the one usually obtained by the method of successive approximations.

32. L. D. Leet and H. G. Taylor. True Horizontal Displacements Near a Five-Ton Blast.

A record of horizontal motion 1400 feet from a five-ton quarry blast was obtained on a critically damped mechanical seismograph with static magnification of 80. True ground motion was computed by integration. A simple, inexpensive integraph which facilitates such computation is described.

The first wave caused the surface to move in a circular path. The motion throughout the first second appears to be the resultant of combined waves of several frequencies and types. Waves from the same blast, recorded at Harvard's fixed Oak Ridge station, at a distance of 187.8 km., are included in the discussion.

33. N. G. Johnson and G. H. Smith. Explosives for Seismic Prospecting.

A test has been devised whereby explosives can be graded visually according to their relative merit for blasting under high water pressures. Representative explosives for seismic prospecting are compared and analyzed by means of this test. One of the

newest developments in explosives for deep-hole shooting is described. Lantern slides will be used to assist in the presentation.

34. C. G. Morgan. Geophysical Studies in Antarctica.

35. R. Beers. Some Photographic Aspects of Seismograph Recording.

The technical sessions were well attended, the audience for each session having been estimated at something over three hundred.

The Society approved the following resolutions:

Whereas—This technical program presented at this Annual Meeting is by far the best presented at any meeting of the Society to date; and

Whereas—The Mid-year Meeting held on November 29, 1936, at Dallas, Texas was not only the Society's first Mid-year Meeting but was also eminently satisfactory from a technical standpoint;

Therefore, be it resolved that—The Society as a whole wishes to express appreciation of the work of the Chairman of the Program and Arrangements Committee, Dr. L. W. Blau; to express regret that illness prevented his attending this meeting; and further, to take pride in his election as President of this Society of Petroleum Geophysicists for the ensuing year.

Whereas—This technical meeting was extremely successful, well attended, and thoroughly enjoyed by all of those members and guests attending;

Therefore, be it resolved that—The Society express appreciation of the courtesy and assistance rendered by the management and employees of the Hotel Tulsa, Tulsa, Oklahoma.

E. E. ROSAIRE

AMENDMENTS TO THE BY-LAWS

The following proposed amendments to the By-Laws of the Society of Petroleum Geophysicists have been recommended and their legality approved by the Executive Committee (E.O.7).

The proposed amendments having been approved by a favorable vote of the Business Committee (E.O.9) they are hereby certified as amendments to the By-Laws and ordered published in the next regular number of the recognized organ of the Society in accordance with the provisions of the existing By-Laws.

JOHN H. WILSON
Secretary-Treasurer.

By-Laws I A 2.

After "regular Society Publication" insert "shall not be eligible to vote" etc.

By-Laws II A 2.

Strike out "a copy of."

By-Laws III A 2.

At end, after "professional cards or otherwise" add "but shall be entitled to receive the regular publication of the Society upon payment of a fee equivalent to that charged an associate member."

IN MEMORIAM

Conrad Schlumberger died on May 9th in Stockholm of a cerebral hemorrhage, after a very short illness. He was born in Guebwiller, Alsace, in 1878. He successively attended in Paris the École Polytechnique and the École Nationale Supérieure des Mines, from which he was graduated in 1904, as a State Mining Engineer (Corps des Mines). In 1906 he was appointed Professor of Physics at the School of Mines of St. Étienne and in 1907 he received the same assignment at the École Supérieure des Mines in Paris, which he retained until the beginning of the World War. He gallantly took part in the whole World War as a Captain and Major in the French artillery. In 1919 he was reinstated Professor of Physics at the École Supérieure des Mines de Paris, which position he resigned in 1923 to devote himself entirely to activities in the field of Applied Geophysics.

It is for his research work, discoveries, and commercial success in this field that the name of Conrad Schlumberger is particularly known to the mining and geological profession at large. After a certain amount of research work which dates from 1908 and the following years, he endeavored to apply his ideas and inventions to solving actual field problems of geology and tectonics. As early as 1913 results of great economic value were achieved, such as the discovery of the Tilva Roch ore body on the properties of the Mines de Bor (Servia). In this respect he was indisputably a pioneer who laid the foundations of the then unknown art of applied geophysics.

After the War, Conrad Schlumberger and his associates, while remaining very active in the field of surface geophysical exploration, became interested in another phase of geophysical prospecting, namely the study of the nature of the formations traversed by a drill hole, by means of physical measurements actually performed at depth in the drill hole. The usefulness of this type of investigation was soon demonstrated, in particular in connection with oil exploration and exploitation. At the present time, electrical logging is a regular feature of the drilling practice in the oil fields and is applied in almost every oil district of the world. The service rendered to the oil industry in efficiency and in saving of time and money is considerable, and Conrad Schlumberger's invention ranks among the few outstanding ones achieved in the field of oil production during the past ten years.

Conrad Schlumberger was deeply interested in all questions pertaining to the oil industry. He was widely known for his competence in this field and was an active member of the American Association of Petroleum Geologists and of the Institution of Petroleum Technologists.

The geophysical profession and the oil industry incur an irreparable loss in his passing.

E. G. LEONARDON